Report No. FHWA-RD-78-32

SPEED ADVISORY INFORMATION FOR REDUCED VISIBILITY CONDITIONS

March 1978
Final Report

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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D.C. 20590

FOREWORD

This report describes the results of field experiments conducted to develop preliminary design specifications for a speed advisory system to be used during periods of reduced visibility.

Research on fog guidance systems is included in the Federally Coordinated Program of Highway Research and Development as Task 4 of Project 1L, "Improved Traffic Operations During Adverse Environmental Conditions." Mr. Richard Schwab is the Project Manager and Mr. Jerry Wachtel is the Task Manager.

Acknowledgement and thanks are given to Mr. Francis D. Lane, who served as principal investigator during the early part of the program, and who provided a significant contribution to the experimental design and data analysis.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each FHWA Regional Office, one copy to each FHWA Division Office, and one copy to each State highway agency. Direct distribution is being made to the Division offices.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA - RD - 78 - 32		

4. Title and Subtitle	5. Report Date: March 1978
Speed Advisory Information for Reduced Visibility Conditions	6. Performing Organization Code
7. Author(s): Donald R. Wagner, Dwayne K. Hofstetter	8. Performing Organization Report No.
9. Performing Organization Name and Address: Oregon State Department of Transportation, State Highway Division, State Highway Building, Salem, OR 97310	10. Work Unit No. (TRAIS): 31L 4032 11. Contract or Grant No.: DOT - FH - 11 - 7950
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. 20590	13. Type of Report and Period Covered: September 1972 to March 1978, Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager: J. Wachtel (HRS-41)

16. Abstract

This project was conducted to develop preliminary design specifications for a speed advisory system for use during periods of reduced visibility (fog). Phase I of the program consisted of developing the necessary facilities, equipment and procedures to conduct controlled experimentation under various levels of fog density. Phase II consisted of a series of interrelated experiments to identify optimum advisory information (sign messages and speed values), and the number, locations, and interconnections between signs which would result in the smoothest traffic flow. Phase III utilizes the information from Phase II, as well as the pertinent literature, to develop preliminary specifications for a full-scale advisory system for use on the public highway.

Phase II contained six separate studies. Study I was concerned with determining the speeds drivers normally drive at various levels of reduced visibilities without special signing. Study II was to determine which of the three major percentile speeds (15th, 50th, 85th) from Study I would produce smoothest traffic flow when used as a posted speed. The main purpose of the third study was to determine driver response when other vehicles are present on the highway under conditions of reduced visibility. The 4th study investigated the effects of different types, amounts and display characteristics of advisory signing. Study V investigated the utility of centerline and edgeline delineation. The final study dealt with the effects of unreliable information presentation by advisory signing systems.

17. Key Words	18. Distribution Statement
Fog Warning Signs Fog Research Research Facilities Driver Characteristics	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	184	

Form DOT F 1700.7 (8-72)

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INTRODUCTION

Restricted driver visibility due to fog and its relationship to safe traffic operation, particularly on high speed freeways, has been a national concern. Although fog accidents account for a small percentage of the total accidents, they often involve many vehicles and attract much public attention. During periods of emergency conditions involving severe weather conditions, changes must be made in vehicular operating characteristics to maintain safe traffic operation.

In Oregon, this problem was illustrated dramatically several years ago by a severe series of chain-reaction rear-end collisions on Interstate 5 near Albany, which involved 44 vehicles. Since that time, we have been involved in three major research programs dealing with reduced visibility. This report is the final report on the largest of three studies.

The Oregon State Highway Division conducted this research program, funded by the Federal Highway Administration, to develop preliminary design specifications for a speed advisory system to be used during periods of reduced visibility. The experiments were directed towards determining both the sign messages and speed values and also the number, locations and interconnections between signs which would result in the optimum traffic flow.

This report details the procedures used in conducting the experiments and the findings and conclusions of the study.

PHASE I - SYSTEMS DEVELOPMENT

Figure 1 contains the major activities required to initiate this program. The tasks or activities are shown as squares. The inputs to the tasks and the outputs which result from the completion of the tasks are shown as ellipses.

Literature Review

The literature review is contained in Appendix A. The major findings indicate that most measures of traffic flow, such as headways and lateral placement are not substantially changed by present techniques of variable message signing under fog conditions. There is some evidence that variability in vehicle speeds can be modified but not to a large extent. The presence of fog tends to reduce vehicle speeds somewhat, and there is a further reduction in speeds when variable message signs are used; but there appears to be a minimum speed of 35-40 MPH (56-64 km/h) below which drivers will not drive regardless of what the posted speed is.

A consistent result of most fog studies is that regardless of the combination of fog conditions and variable message signs used, the drivers will travel at a speed in excess of what is considered safe under the limited visibility condition.

Test Site Selection

Prior to the start of the program, a preliminary survey was conducted to indentify a suitable area in which to locate the test site. The requirements included that the area contain an adequate road system on which to conduct the tests, but that it also be located away from public highways. After reviewing a number of alternatives, the E. E. Wilson Game Management Area, Benton County, Oregon, was selected as the most promising. The game area, administered by the Oregon State Game Commission, is located on an abandoned army base midway between Corvallis and Monmouth on Oregon Highway 99W. The road system from the base was still intact, and while easily accessible, the area was away from public highways.

Coordination with the Game Commission was carried out and permission to use and modify the area as required was received. Coordination was also conducted with private individuals who owned property bounding the area and who have access to their properties through the test site. Procedures were worked out to avoid conflicts when the area was in use.

Historical Weather Data

Since preliminary information indicated that both the size and operation of fog generating equipment would be highly dependent upon weather, overall patterns for the general area were obtained from monthly weather summaries from the National Weather Service Stations at the

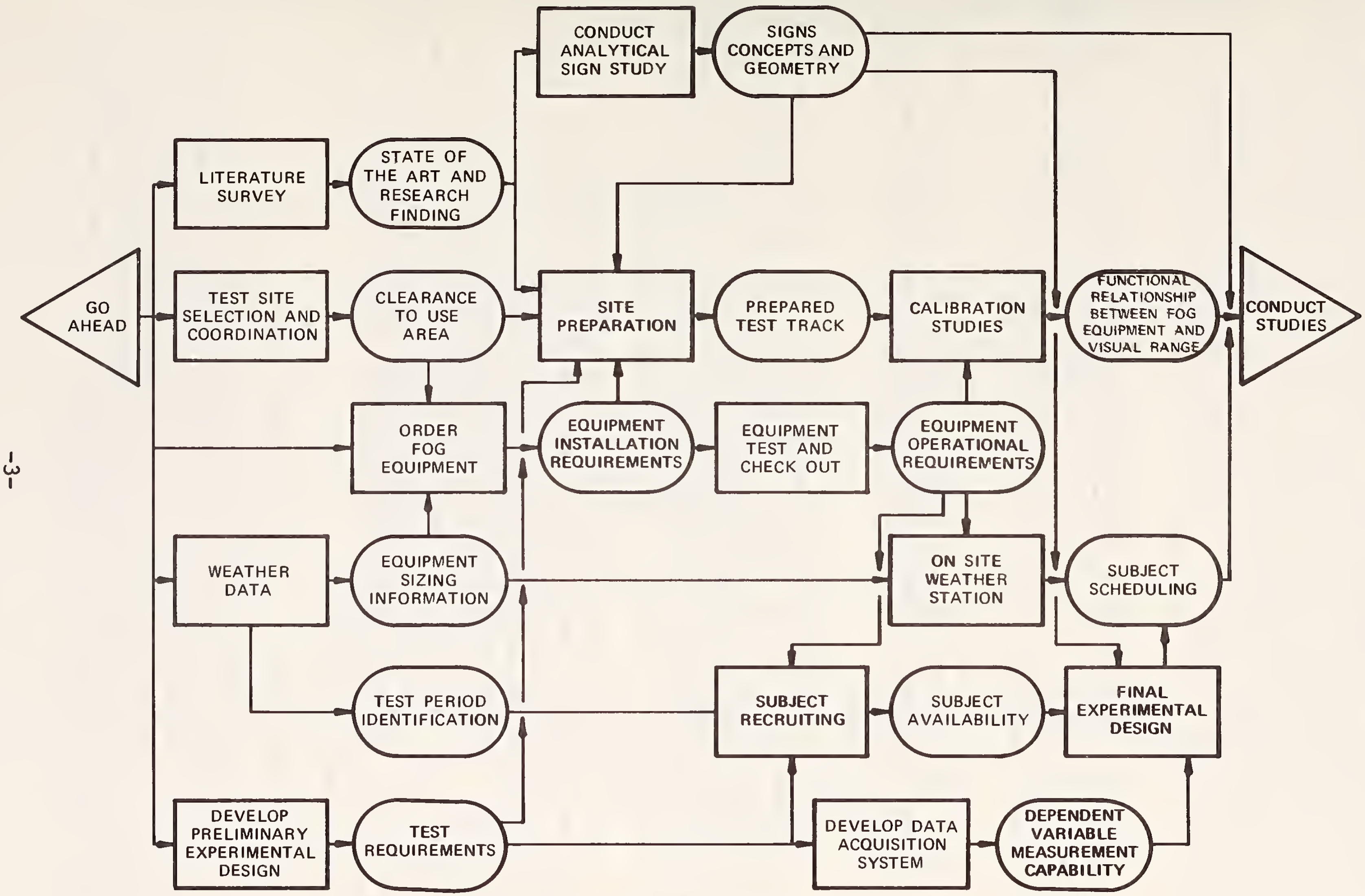


Figure 1. Svstems Development (Flow Diagram)

Portland, Salem and Eugene airports. More specific data was obtained from Oregon State University's Hyslop Agronomy Farm, located approximately three miles southeast of the test site. This data consisted of temperature, relative humidity, wind speed and wind direction for two-hour increments for the years 1964 to 1972. Based on this data, the fog generating equipment was sized and the system designed to produce visibilities as low as 50 feet (15 m) assuming favorable atmospheric conditions. The performance curves for the system are contained in Figure 2. These curves are based on a 2.5 MPH (4.0 km/h) west wind.

The data also indicated that the prime operating periods would be between 4 a.m. and 8 a.m., late afternoon and at dusk during the months of September through April. During these periods the temperature and relative humidity were in acceptable ranges with a prevailing west wind. The summer months appeared to be too dry and too warm.

To provide current data, an onsite weather station was obtained on loan from the National Weather Service. This station provided a continuous recording of wind speed and direction as well as temperature and relative humidity. The system was subsequently replaced by one on loan from the FHWA.

While the historical data proved adequate for sizing the fog system, the data obtained from the onsite equipment showed that substantial differences existed in the weather patterns between the two locations. The data from the Hyslop Farm indicated a predominate west wind while the site data indicated almost a due south wind during the winter months and a northerly wind during the summer months. The differences between the two areas appeared to be due to their different topographies.

Due to these factors and the layout of the test site and fog generating equipment (see below) a major revision was required in the operating schedule. The prime operating period was found to be between June and October and between the hours of 12 midnight and 6 a.m. for night conditions and from dawn to 9 a.m. or from 3 p.m. to dark for day conditions. During these periods, the temperature and humidity were generally in an acceptable range and a sufficient west vector existed in the wind to maintain the generated fog along the test road. Even during these periods, however, substantial shifting of the wind did occur on a random basis. This resulted in variances in the fog density and an occasional delay in testing.

Fog Generating System

The fog generating systme was obtained from Mee Industries (Rosemead, California). This system was designed to produce a man-made fog which closely duplicated natural fog. The Mee system was based upon the principle of pressurizing water to approximately 550 psi (40 kg/cm^2) and forcing it through patented fog nozzles which produce water droplets in a size range of 10-40 microns. The primary use for these systems has been in agriculture for frost protection.

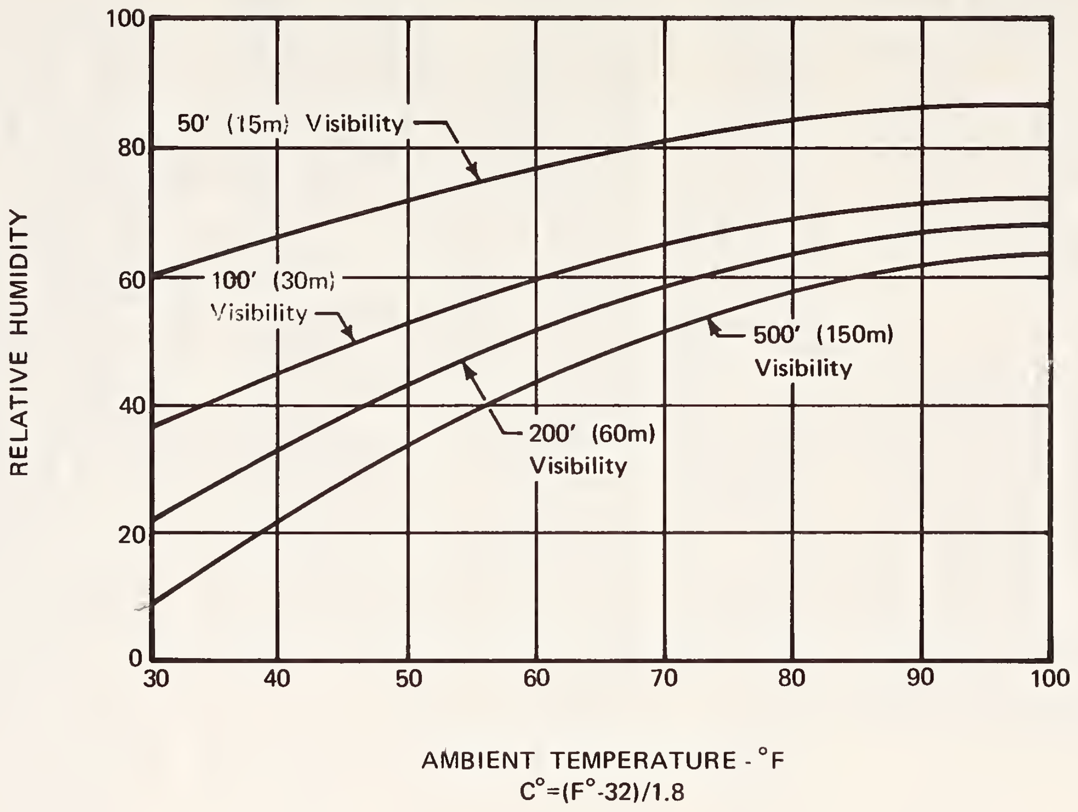


Figure 2. Visibility Range of Fog Generating System

The fog system consisted of two major subsystems, the suspension system and the generating system. The suspension system which held the fog lines consisted of six Douglas Fir utility poles which extend 25 feet (8 m) above the ground. The poles were on 200 foot (60 m) centers over the 1000 foot (305 m) test range. The suspension system was located 60 feet (18 m) west of the edge of the test road. The location of the suspension system with respect to the test track is shown in Appendix B.

The fog generating subsystem consisted of four main components; a filtration system, a high-pressure pump motor drive, a distribution system, and the fog modules containing the individual fog nozzles. Figure 3 contains a schematic diagram of the system. Figure 4 is a photograph of the essential components. The photo was taken prior to the construction of the equipment shelter. The fog modules can be seen in the background suspended between the poles of the suspension system. The individual nozzles appear as small dots on the pipes within each module.

Water for the system, 130 gallons per minute (490 liter/min.) was obtained by tapping a 12-inch (30 cm) water main located 4,000 feet (1.3 km) east of the test site. A shut-off valve and back flow preventer were located at the tap. The water was transported to the test site through 4-inch (10 cm) aluminum irrigation pipes.

Prior to entering the system, the water was passed through a 7½ horsepower (5593 W) booster pump (220 VAC, 3-phase, 20 amp.) in order to maintain an influent requirement of 130 gallons per minute (490 liter/minute) at 60 psi (4 kg/cm^2). The water was then filtered by means of a high rate sand filter (with back-flushing provisions) to a maximum particle size of 40 microns. Following the sand filter a cartridge type filter was provided as a safety back-up. The high pressure pump/motor drive consisted of a rotary type pump driven by a 75 horsepower (55,923 W) electric motor (440 VAC, 3-phase, 90 amp.). This system boosted the water pressure from 130 gpm (490 liter/min.) at 60 psi (4 kg/cm^2) to 130 gpm (490 liter/min.) at 550 psi (39 kg/cm^2). The distribution system distributed the water from the high-pressure pump to the fog modules suspended above and along the test track. This system also provided a means for density control.

To accomplish density control, the distribution system was divided into five discrete lines at the pump output. The lines were identified as the green, blue, black, yellow and red lines. Each line was individually valved to permit the lines to be operated independently. When a line was opened, water flowed through the valve towards the ends of the fog system by means of underground feeder lines. At each pole location, tees were provided in the feeder lines from which risers carried the water to the top of the pole. At the top the risers were again teed to feed water to the fog modules to the left and right of the poles in dipole fashion.

The fog modules consisted of sections of PVC pipe containing the individual fog nozzles. Each module contained five pipes (corresponding

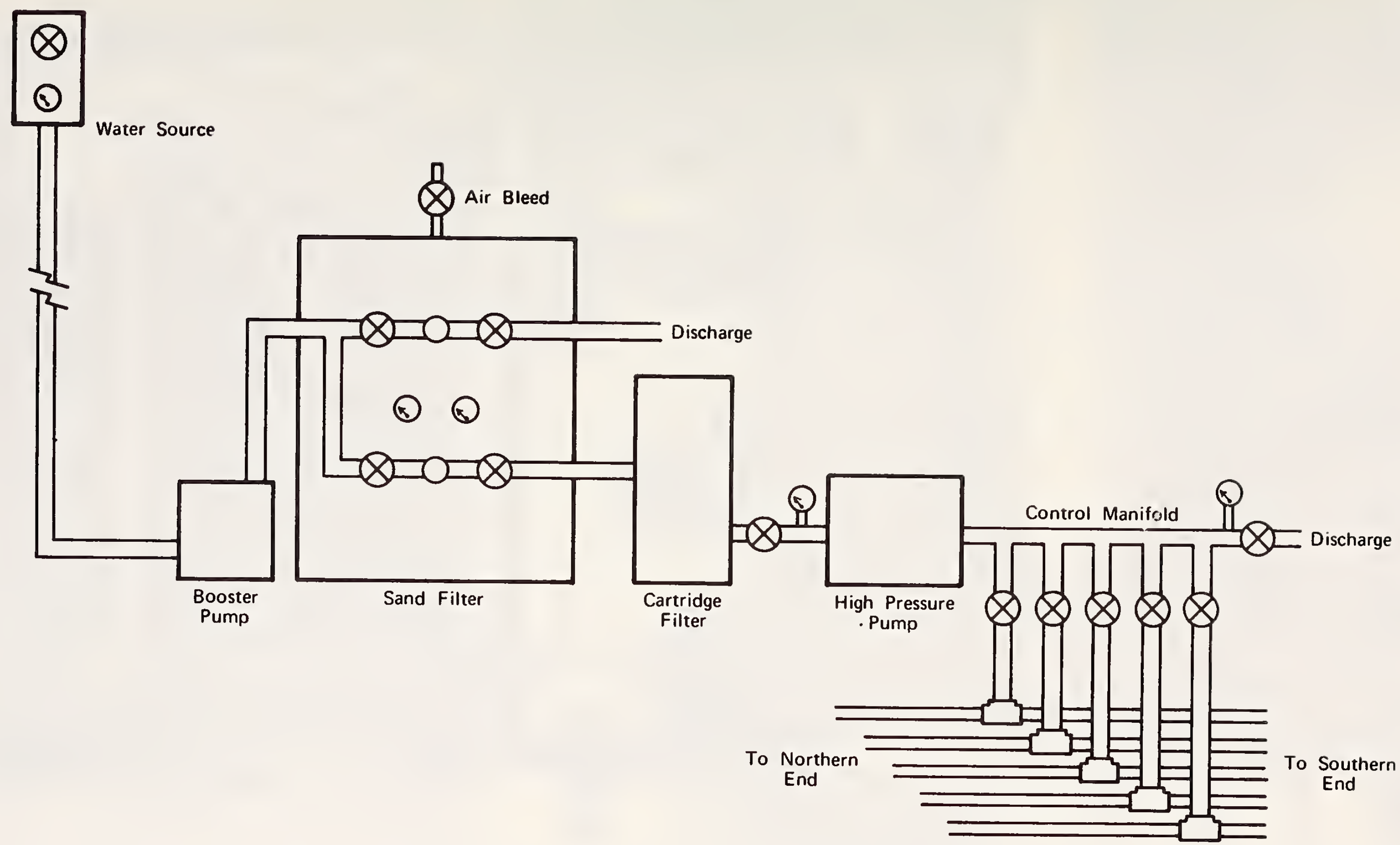


Figure 3. Fog Generating System (Schematic Diagram)

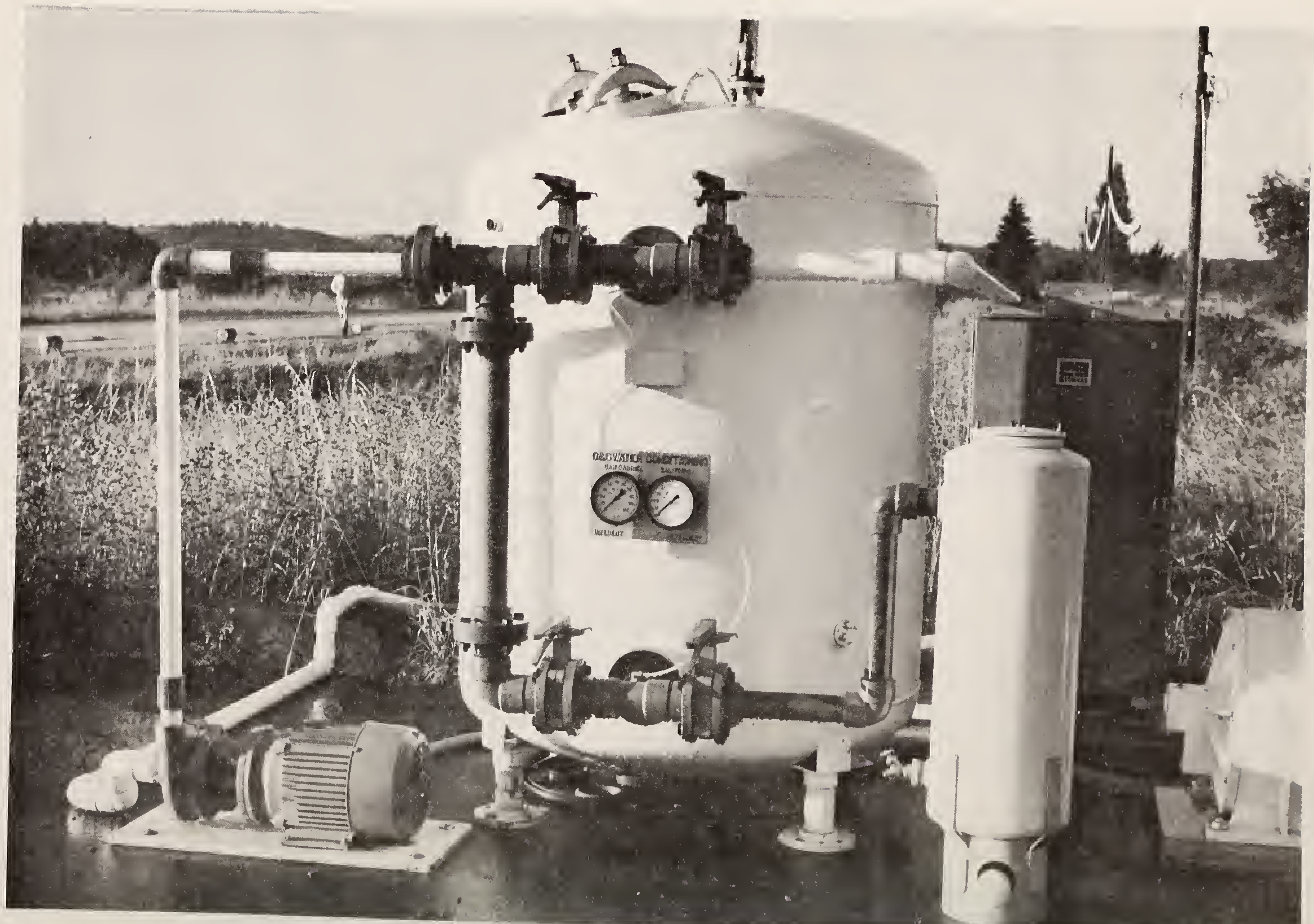


Figure 4. Photograph of Fog Generating System Components

to the five lines) bracketed together. Each module was 100 feet (30 m) long and the pipes capped at the end. Two modules were suspended between pairs of the suspension system poles by means of a messenger cable. Water was fed to the modules from the pole end.

The five pipes within a module corresponded to one of the lines (i.e. green, blue, black, yellow or red). The fog nozzles were threaded into the pipes with the number per foot depending on the particular line. For the system as a whole there were 3,550 nozzles or an average of 3.5 nozzles per foot (11.5 nozzles per meter). Each nozzle dispensed 0.036 gpm (0.136 liter/min.) of water as fog. The green line was the heaviest containing an average of 1.5 nozzles per foot (4.9 nozzles per meter). The blue and black contained .75 per foot (2.5 per meter) while the red and yellow contained .3 and .2 per foot (0.98 and 0.66 per meter).

Density control then was obtained by manipulating the number and which particular lines were opened. When a valve was opened, water was fed to the corresponding pipe in each module along the entire 1000 foot (300 m) length of the system. The pumps were located in the center of the system to minimize pressure differentials.

If the dense fog was required, either multiple lines and/or the heavy lines were used. If less dense fog was required, few and/or the light lines were used. Once a setting was achieved, the density could be varied as required by further manipulation of the valves.

The system was reported by Mee Industries to be approximately 80% efficient. That is, 80% of the 130 gpm (490 liter/min.) of water is generated as fog. The remaining 20% is lost at the modules in the form of rain.

Preliminary Experimental Designs

Based upon the contract requirements and literature review, a set of preliminary experimental designs was developed. The objective of this effort was to identify the test requirements as far as they influenced the test site preparation and the development of the data acquisition system. These plans were also used as working papers in arriving at the final experimental designs. The final designs are covered below.

Analytical Sign Study

To guide the design and preparation of the test site, a preliminary analytical sign study was conducted to develop sign concepts. This study consisted of a systematic analysis of hazardous driving situations and was directed towards identifying the information required by a driver to negotiate a hazard. The requirements developed consisted of informing a driver of the following:

1) a hazard exists
2) the nature of the hazard
3) the extent or degree of the hazard (either qualitative or quantative)

4) the distance over which it exists
5a) alternative routes around the hazard area
5b) what the driver is required to do (and/or not do) to negotiate the hazardous area safely
6) feedback of some form comparing his performance with the requirements and instructions for error correction
7) an indication that the driver is out of the hazard area

Associated with this information transfer were the messages used, the number of signs required, their locations, and interconnections between signs. These parameters were used to guide the design and lay out the test site.

Test Site Preparation

An evaluation of the roads located within the game area was made in terms of the tests and operational requirements. Based upon this analysis, two roads identified as "A" and "B" Streets (old military designation) were selected. Appendix B contains a drawing showing the major features of the test roads. Each road is 1.09 miles (1.75 km) long and they are approximately 600 feet (180 m) apart. "B" Street was selected as the main road due to its width of 36 feet (11 m), relative flatness, and overall condition. "A" Street, 24 feet (7 m) wide, was selected as a return road. Although the roads were in generally good condition, considerable clearing, cleaning and patching of both streets were required. The curve at the end of "B" Street was widened to permit higher speeds. The connecting road between "A" and "B" Streets was cleared for the purpose of this test.

In the layout of "B" Street, five zones were considered; acceleration, signing, deceleration, fog and acceleration. In establishing the length of these zones, an attempt was made to balance the various requirements of each. The acceleration and deceleration zones were established to permit a wide range of vehicle operations in an attempt to minimize any restrictions on the driver due to the roads. The fog zone was established to permit a reliable estimate of drivers reactions to be obtained. The signing zone was sized to accomodate a variety of potential signing plans. The length of each zone is as shown in Appendix B.

The roads were configured and marked as two lanes of divided highway in one direction. The striping, delineation and basic signing plans are contained in Appendix B. The striping consisted of left (solid yellow) and right (solid white) shoulder stripes and a dashed white center line. The lanes on "B" Street were 12 feet (4 m) wide; the lanes on "A" Street were 11 feet (3 m) wide. "B" Street also contained white sight posts with white reflectors its entire length and around the curve at the south end. Flexible rubber guide posts were provided on the south curve for safety purposes.

The signs were located as shown in Appendix B. In each case the signs conform to the Manual on Uniform Traffic Control Devices. The other major features at the test site included a 10' by 35' (3 m by 10 m) office trailer located at the intersection of "B" Street and the connecting road.

The trailer served as both a field office and a subject briefing and debriefing area. The trailer could accomodate approximately 12 subjects. The control center, located in the middle of the fog zone, was a 15' by 30' (5 m by 9 m) frame building constructed over the major components of the fog generating system. The center also housed the Data Acquisition System and served as the central point from which tests were conducted.

Equipment Test and Checkout

The equipment testing and checkout activities consisted of operating the system under a variety of conditions to gain experience and to learn its operating characteristics. Experience with the fog system showed it to be an effective fog generator which met the design requirements of Figure 2 given the necessary atmospheric conditions. Under these conditions (a maximum 2.5 MPH (4.0 km/hr.) west wind), the fog was generated uniformly over the entire length of the system. As it was generated, the fog was moved by the wind over the road as a rectangular shaped volume approximately 1,000 feet (300 m) long, 20 feet (6 m) deep and 60 feet (18 m) or more wide. The most noticeable difference between the generated and natural fog was that the generated fog tended to be somewhat wetter. Figure 5 shows the fog bank from the position of an approaching vehicle while Figure 6 shows the system in operation. Figure 7 shows a vehicle in a fog bank from a distance of approximately 30 feet (9 m) under daylight conditions.

While ideal weather conditions have been observed at the test site, they were rare. From an experimental standpoint, the most critical factors affecting the system's satisfactory operation were wind speed and direction. Depending on these variables, the conditions ranged from impossible to conduct tests because roads could not be fogged in (wind blowing in wrong direction) through conditions in which the tests could be conducted under ideal conditions.

If a west vector was present in the wind movement, the road could be fogged in to some degree and tests conducted. However, under these conditions, the fog takes on the shape of a parallelagram in the direction of the wind's movement. This caused the leading and trailing edges of the fog bank to be in different locations at different times. The most typical condition observed at the test site during the summer months was a northwest to a north-northwest wind which moved the fog bank south with respect to the fog generating system. This condition also resulted in differences in densities between the north and south sections of the road.

Wind speed affected both the density and quality of the fog in terms of its uniformity. Higher wind speeds pass more air through the area which must be saturated resulting in less dense fog. The quality of the fog was also reduced in that visual ranges may change rapidly and clear or patchy areas developed. Changes in either wind speed or direction had their obvious effects in addition to causing complex interactions. In addition to the overall wind patterns, ground currents were present which resulted in localized movements of the fog.

Figure 5. Photograph of Fog Bank from Position of an Approaching Car

Fiqure 6. Photograph of Fog System in Operation

Figure 7. Vehicle in Fog Bank from a Distance of 30 Feet (Daylight Conditions)

Since physical methods to control these factors are not feasible, procedural methods were developed to minimize their effects. These included scheduling tests during optimum periods and cancelling if necessary, using larger sample sizes, measuring the fog densities in both the north and south sections as soon as the vehicles passed through and physically measuring the position of the leading edge.

In order to obtain data concerning the uniformity of the fog bank under operating conditions, density measures were taken simultaneously from two positions. This data is contained in Figure 8. Position I was located in the center of the fog bank looking south with a potential range of 500 feet (150 m). Position II was located 250 feet (75 m) south of Position I with a potential range of 250 feet (75 m). The tests were conducted on a typical night using the night targets (see below). The numerals in Figure 8 represent the frequencies with which the corresponding pairs of ranges were observed. Although some variability exists, Figure 8 shows a substantial agreement in the visual ranges determined from the two positions. These results indicated at least a reasonable degree of uniform density.

Calibration Studies

Concurrent with the equipment testing and checkout, methods were developed to measure the visual range. To accomplish this, a survey was made of the available literature and discussions were held with practioners in the area. It was concluded that while visual standards are not well defined, the most universally accepted targets are black 2% contrast targets for daylight conditions, and unfocused lights of approximately 25-candle power for night conditions. However, no information could be found on the relationship of the ranges obtained by the two methods.

Day and night targets were developed. The day targets were constructed of sheets of ½-inch (1.3 cm) exterior plywood, mounted on portable stands. The targets were sized to maintain one-half a degree of visual angle both vertically and horizontally at 50-foot (15 m) increments from 50 to 500 feet (15 m to 150 m) from a fixed eye point. The targets were painted with a flat black exterior paint to provide an approximately 2% contrast.

The night targets consisted of 25-candle power, non-focused lights mounted on portable stands also at 50-foot (15 m) increments. The lights (General Electric 40G/W 150 VAC) were mounted in water proof sockets attached to 12-inch (30 cm) backboards and covered with 8-inch (20 cm) traffic signal hoods for weather protection. No. 10 gauge wire was used throughout and the system was wired from the center to minimize voltage drop. Separate sets of targets were constructed for the north and south sections of the fog zone with the eye point located in the center of the zone. The targets were set along the west edge of the test track. The controls for turning the night targets on and off were located near the eye point.

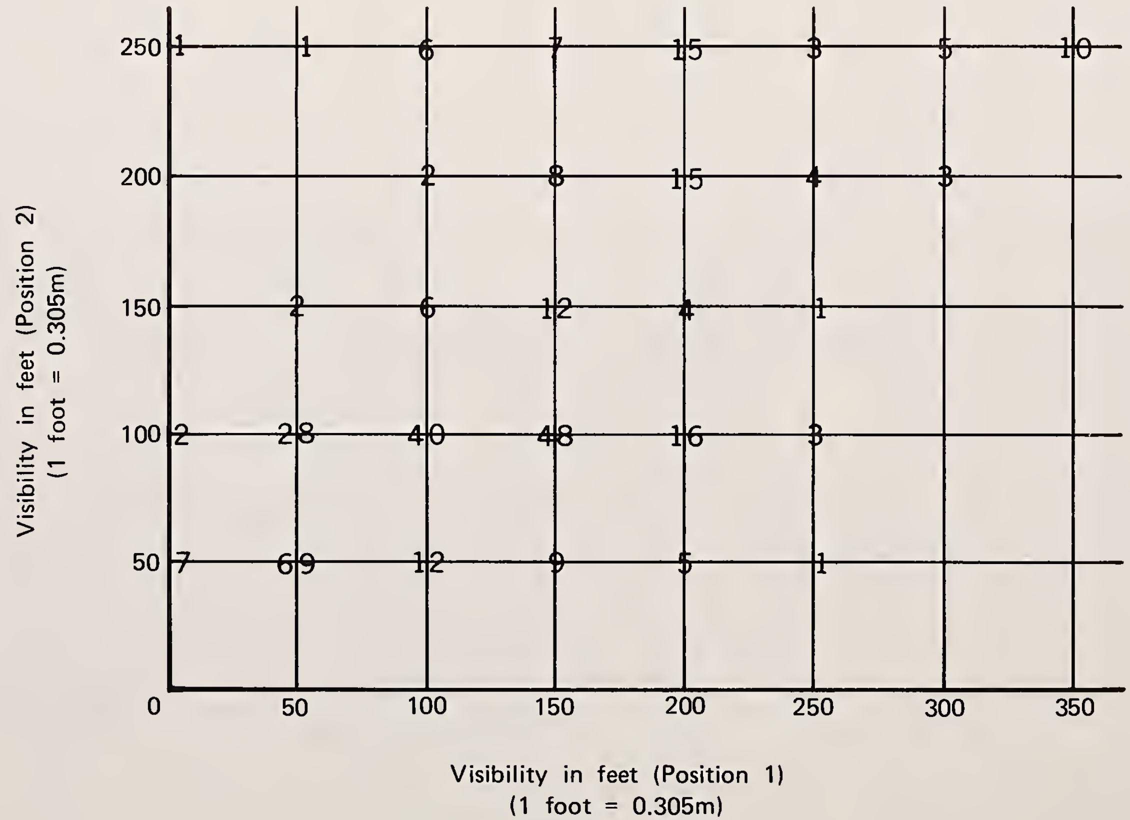


Figure 8. Scatter Diagram of Visibilities Obtained from Two Positions Using Night Targets

Visual range was determined by the number of targets (either day or night, depending on conditions) which could be seen at any particular time and converting this number into distance. Criteria were developed to eliminate ambiguity to the extent possible. It should be noted that the visual ranges thus obtained represent "at least" readings and have a potential error of approximately 50 feet (15 m). For example, a reading of 200 feet (60 m) represents a visibility of at least 200 feet (60 m). The actual visibility could be greater than 200 (60 m) but less than 250 feet (75 m).

In an attempt to obtain comparisons between the two methods of determining visual range, readings were taken simultaneously for the two sets of targets during daylight conditions. The results are contained in Figure 9. The numbers represent the frequencies with which the corresponding pairs of ranges were observed. The data indicates a 1:1 correspondence for visibilities above 200 feet (60 m). For visibilities less than 200 feet (60 m), the lights result in a slightly greater range of approximately 30 feet (9 m).

For the night conditions a direct comparison could not be made beyond a certain level of illumination when the black day targets could no longer be seen. However, up to that point, the relationship between the two was of no interest. In an attempt to obtain such information, pairs of readings were taken with the two methods of measurement during daylight runs which were continued after dark. Unfortunately, an illumination meter was not available to obtain objective brightness levels. In addition, the tests were started at different times and progressed at different rates so that a time base could not be used.

To overcome these limitations, the visual readings were grouped into groups of five runs each from the start of the test until the daylight target could no longer be seen. Although the sample size was small, a fairly consistent pattern emerged. The daylight target resulted in a slightly longer average range at the start of the test, but the difference between them decreased through a point of indifference after which the night target resulted in progressively greater ranges. The average ranges obtained from the two sets of targets were computed for each five run blocks and the difference between them obtained. The data is contained in Figure 10.

Figure 11 shows the results obtained in a comparison between the night targets and standard taillights and brakelights. Over 800 sightings were utitized in this comparison. Figure 11 shows that the 32 candlepower red brakelight and the night targets exhibit a one to one relationship for visibilities under 250 feet (75m), but the brakelight was slightly more visible above 250 feet (75 m). The 3 candlepower taillight exhibited a constantly lower reading than the targets ranging from a 25 foot (8 m) difference in low visibilities to 50 feet (15 m) at 500 foot visibilities (150 m).

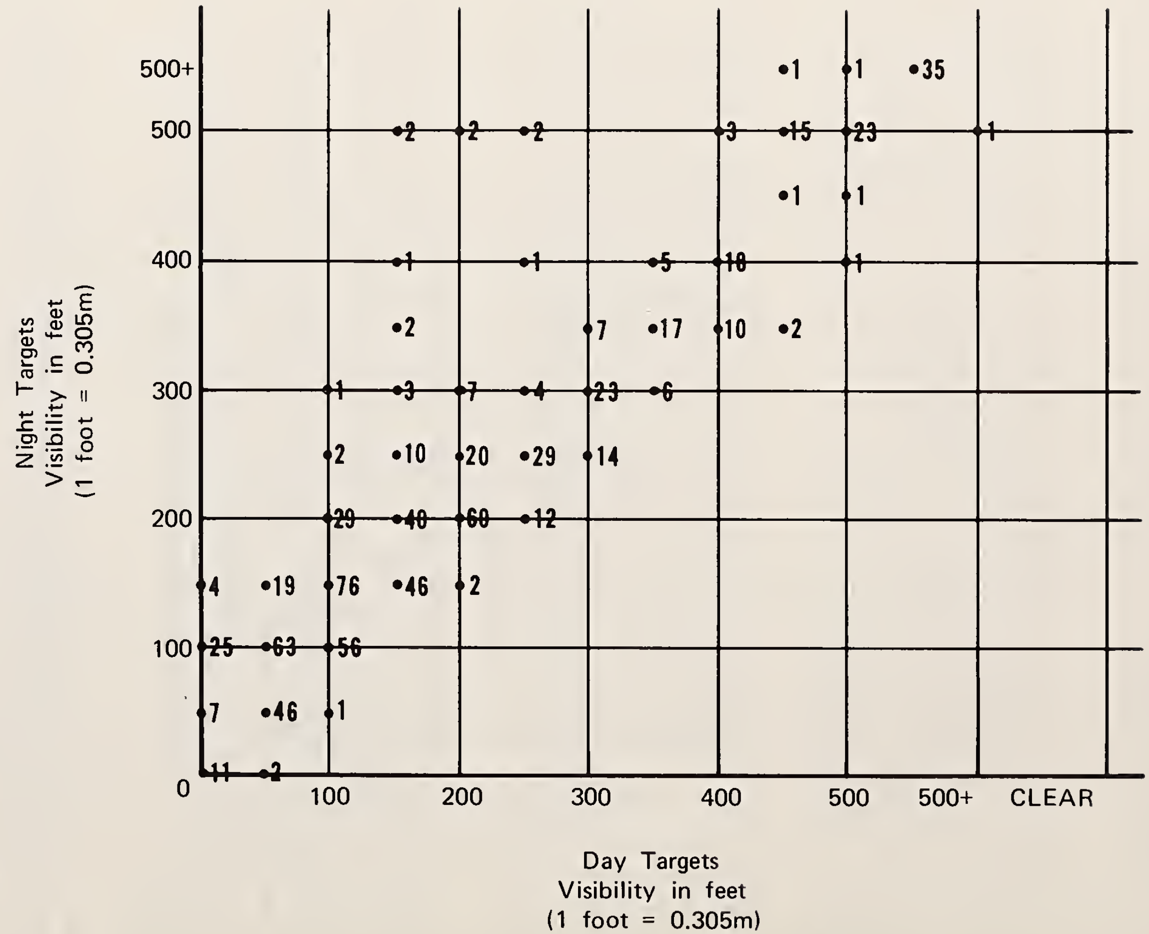


Figure 9. Scatter Diagram of Visibilities Obtained from Day and Night Targets During Day Conditions

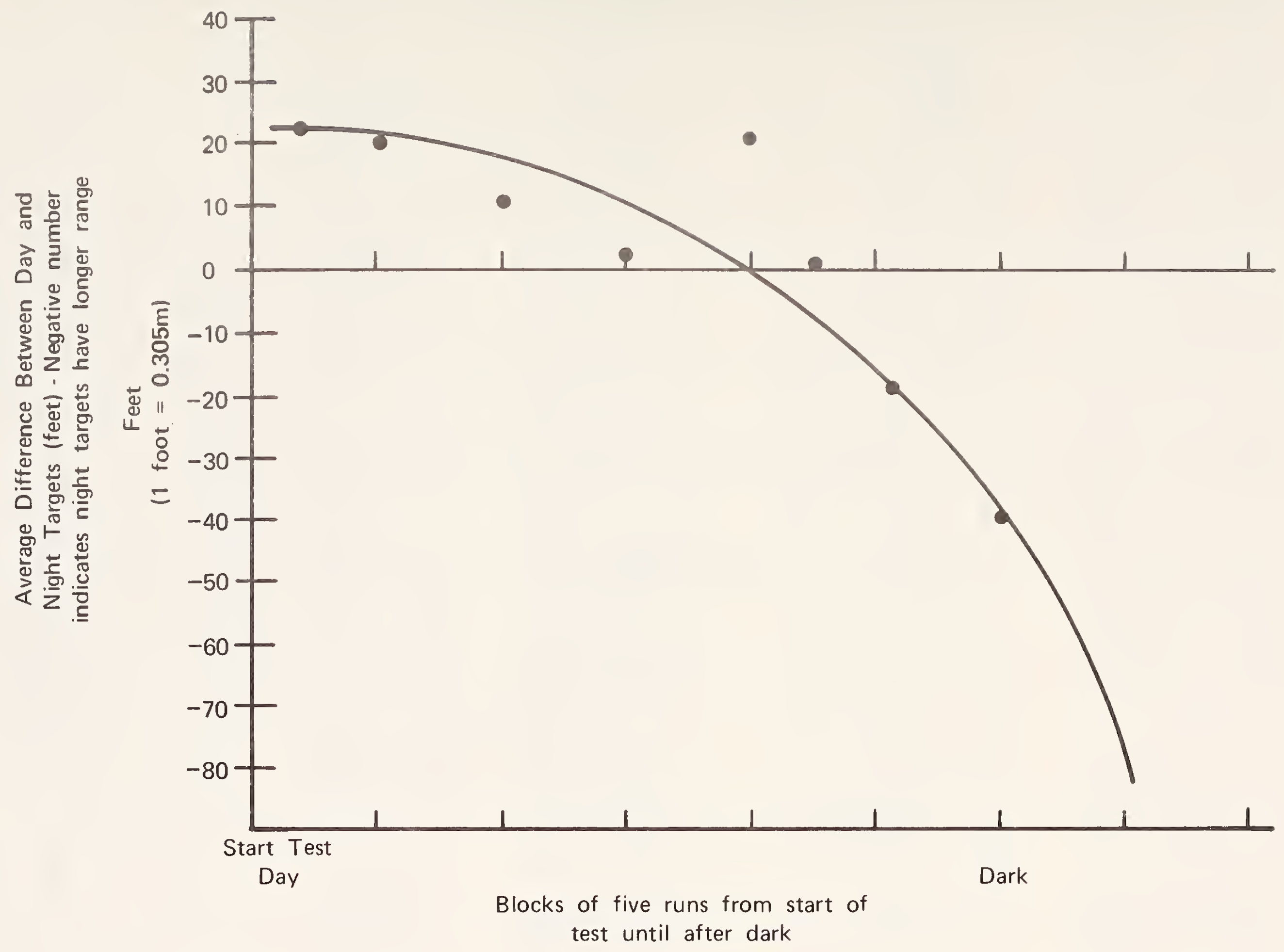


Figure 10. Relationship Between Day and Night Targets When Going from a Day to a Night Condiiton

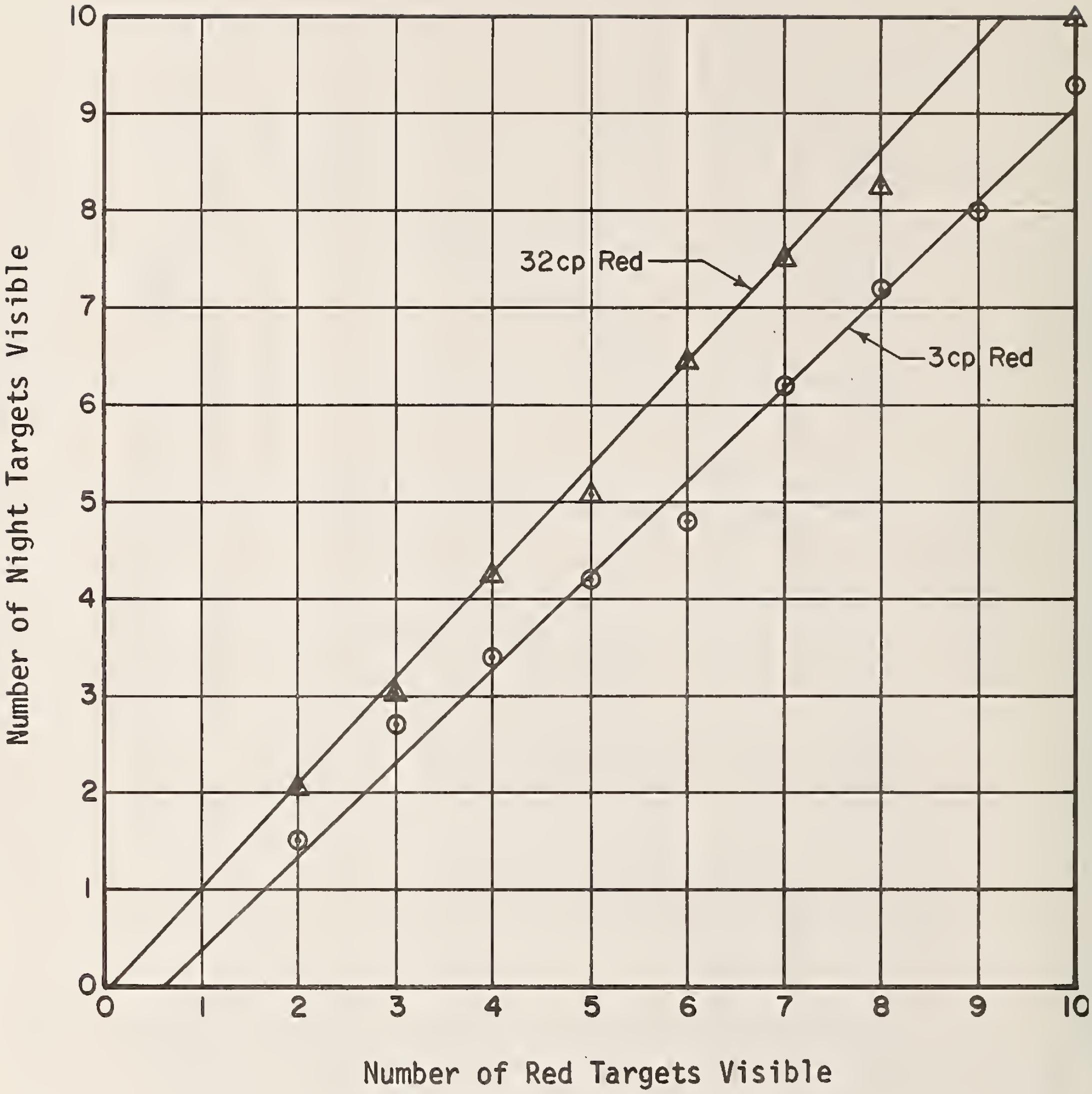


Figure 11. Comparison of Night Target with Brakelights and Taillights

Subject Recruiting

The subjects used during the experimental phase of this program were obtained from the normal Oregon driving population located in the general vicinity of the test site through a subject recruiting procedure. The test requirements (i.e. representative sample, the number of subjects involved, etc.) precluded the use of volunteer subjects. Consequently, notices and application form were placed in the Student Employment Offices at Oregon State University, Oregon College of Education, Linn-Benton Community College, and the State Employment Offices in Corvallis and Albany. In addition, the application forms were run as newspaper ads in four area newspapers. A copy of the application form is contained in Appendix C.

In all, over 1,000 individuals submitted application forms. Of these, approximately half were males and half were females. The age of the respondents ranged from 16 to 76 for the males and from 16 to 59 for the females. Subjects for the individual tests were randomly drawn from the subject pool. For the purpose of the tests, the subjects were hired as part-time state employees. Insurance covering the subjects automobiles was also provided.

Data Acquisition System

The components of the data acquisition system were the most difficult to integrate into a reliable system. Based upon the preliminary experimental design, it was determined that the subject's response to the signing and fog in terms of the speed records would be the primary dependent variable for this study. Secondary information consisted of the subject's comments concerning the condition they encountered during a post-test interview.

To measure the subjects' speed, it was initially intended to use two traffic radars (Stephenson Mark IV) with 1,500 foot (455 m) ranges. Pressure sensitive tape switches (Tape Switch Corporation of America, L.I., N.Y.) were also planned as position markers to determine the vehicle locations on the test track against which the speeds could be correlated. The recording system was to have included an Esterline Angus, Speed Servo II, two channel strip chart recorder with an event pen. Each radar was to be recorded on a separate channel with the position markers recorded on the event pen. The radars would be positioned to provide continuous radar coverage over the entire sign and fog zones. Since the radar signals are continuous and a substantial amount of data would be generated, provisions for automatic data processing were included through the use of a Lockheed Electronics four-channel FM tape recorder. This recorder was obtained on loan from the FHWA. The necessary interface electronics were designed and constructed to permit recording the radar signals on both the Esterline Angus and on two of the channels of the Lockheed Recorder. The position indicators were recorded on a third channel of the Lockheed with the fourth as a backup. Provisions were made and the necessary programming developed for the analog to digital conversion of the radar signals on the Oregon State University Electrical Engineering EAI (Hybrid) Computer. The

statistical analysis would then be done on OSU's CDC 3600 computer.

The first difficulty encountered was in the range and quality of the radar signals. Although the test track was relatively flat throughout the critical areas, the maximum range which could be obtained from the radars was approximately 800 feet (245 m) with an average of about 600 feet (155 m). However, the range varied according to the position on the road with one radar having a range of only 400 feet (120 m). No definitive explanation has been determined for these conditions since the radars performed satisfactorily outside the test area. However, the State Game Commission has reported abnormal radio operations in the area.

To compensate for this condition, extensive tests were conducted to determine the optimum number and positioning (location, height above the ground, side of road, aim angle and aim direction) of the radars which would be required to provide the necessary coverage. Based on these studies, it was determined that four radars were required. The location of the radars is shown in Appendix B. The radars were mounted 5 feet (1.5 m) above the ground and 1 foot (.3 m) west of the road. Small field boxes were provided at each of the four radar locations to house the readout modules and power supplies (12 volt batteries). The radar signals were transmitted to the recorders located in the Control Center by way of shielded cable.

To interface the four radars with the two channel Esterline Angus and Lockheed Recorder, a radar switching box was designed and built. This box provided for sequential switching of the signals from the four radars as a vehicle proceeds along the test road by means of three Radar Switching Tubes (also shown in Appendix B).

In its initial position, the signals from Radar 1 and Radar 2 were recorded as the vehicle proceeds along the road. When the vehicle passes over Radar Switch 1, located 100 feet (30 m) beyond Radar 2, the signal from Radar 1 was turned off and the signal from Radar 3 turned on. The vehicle was then tracked by Radars 2 and 3 until it passes over Radar Switch 2. This switch, located 100 feet (30 m) beyond Radar 3, turned the signal from Radar 2 off and the signal from Radar 4 on. The vehicle was then tracked on Radars 3 and 4 until it cleared the fog area and passed over Radar Switch 3, located 400 feet (120 m) beyond the fog zone. This switch returned the box to its initial position in preparation for the next vehicle (i.e., the signals from Radars 1 and 2 on and the signals from Radars 3 and 4 off).

While this technique provided for adequate coverage, the quality of the radar signals was still low in terms of noise, the most severe of which are phase cancellations. These caused the radar return to momentarily drop out and they occured on an almost random basis. To minimize these cancellations and to improve the overall quality of the radar returns, 18-inch (45 cm) radar corner reflectors were constructed from sheet metal and fitted with brackets for window mounting. One car top mount was also constructed for vehicles which could not accommodate window mounts.

The second difficulty encountered was with the tape switches. These switches were pressure sensitive, normally open which complete a circuit when closed. The switches were secured to the road by way of spray adhesive and double backed tape. The entire installation was then covered with a double layer of duct tape.

Experience with the tape switches showed them to be highly susceptible to failure. Since the tape switches were normally open and were interconnected, a short circuit in one resulted in the entire system being out. Again, while a definitive explanation has not been determined for these conditions, it was suspected that studded tires or stones caused either a puncture in the thin protective covering or a dimpling between the contacts. In addition to their cost and the short life expectancy which was observed, the installation of the tape switches required that the pavement be dry which made them difficult to replace in the wet climate of Oregon. Consequently, the tape switches were replaced with pneumatic road tubes. Although more noticeable (both visually and in terms of the sound they made when a vehicle passed over them) than the tape switches, the reliability of the pneumatic tubes justified their use.

The third major problem encountered was with the Lockheed Recorder. Numerous difficulties were experienced in its operation, both individually and with the other system components. Since satisfactory operation could not be achieved after numerous attempts, the use of the recorder was abandoned.

A schematic diagram of the final configuration of the Data Acquisition System is contained in Figure 12. The signals from the radars were received by the radar switching box. In addition to performing the switching function as outlined above, the box also served as an interface to the Esterline Angus and provided a means to compensate the radar signals for line loss. Radars 1 and 3 were recorded on Channel 1 of the Esterline Angus and Radars 2 and 4 on Channel 2.

The event box served as an interface for the road tubes or position markers. The tubes were located every 300 feet (90 m) through the sign zone and every 150 feet (45 m) through the fog zone. The last tube was located 300 feet (90 m) beyond the fog. The location of the tubes is shown in Appendix B. When a tube was activated, the event box pulsed the event pen on the Esterline Angus. The last tube also served as an end-of-track indicator which would ring bells located in the Control Center and at the trailer to indicate that a vehicle had cleared the fog area. A counter was also incremented to provide a cumulative count of the runs made.

Esterline Angus Equal Division Chart Paper (No. 240514) was used to record the subjects speed. The Y axis represented speeds from 1 to 100 MPH in one-half mile increments (2 to 160 km/h in 0.8 km/h increments). The X axis represented time and is ruled in 1-inch (2.5 cm) increments. The recorder was normally operated at one-half inch per second (1.3 cm/sec.) making each increment two seconds of time.

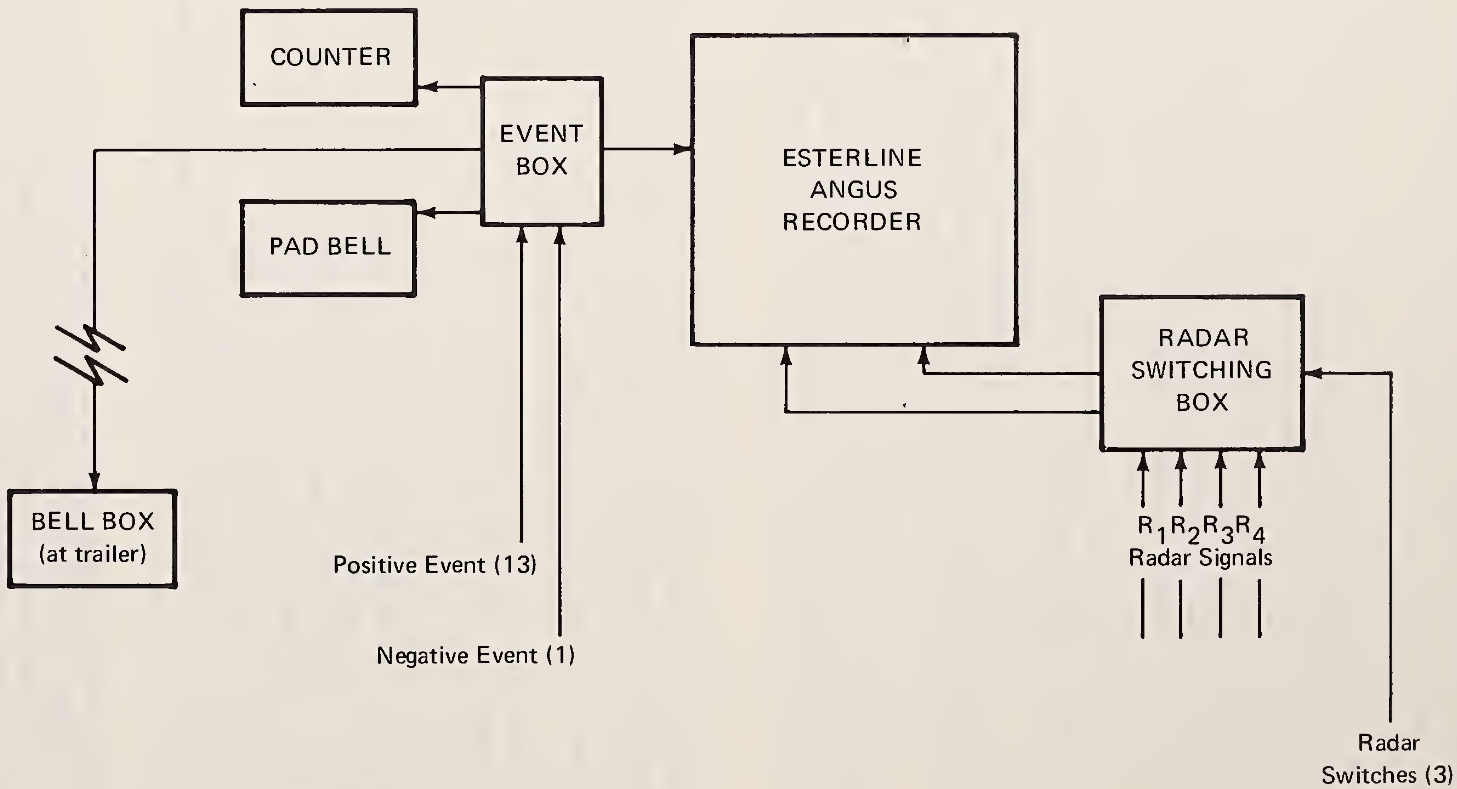


Figure 12. Data Acquisition System (Schematic Diagram)

To evaluate the accuracy of the overall system, extensive tests were conducted with a calibrated vehicle. The system was found to have an accurate operating range from approximately 2 MPH to 70 MPH (3 to 112 km/h) or better. Below 2 MPH (3 km/h) the signal became ragged. Below approximately 1 MPH (2 km/h) vehicles were difficult to track and it was not possible to distinguish these speeds from a stopped vehicle.

Without the Lockheed Recorder, a manual method for analog to digital conversion of the speed data was required. The method developed approximated the speed curve by a series of straight lines. The length and number of lines needed was determined by the characteristics of the speed curve being analyzed. For flat, relatively constant speed curves, a few long segments were adequate. For variable speed curves, many short segments were required.

The flow diagrams for the conversion procedure is contained in Figure 13. The procedure started with the Esterline Angus Charts for each experimental session. The charts were cut into individual runs and the car-run number recorded (if not already present) and a unique sequence number assigned. Each chart was inspected and drop-outs (phase cancellations) or other noisy spots were hand smoothed. Any charts which were too broken to be reliably hand smoothed were rejected.

The data points were determined according to the procedures outlined in Appendix D. Since the Esterline Angus was operated at a constant speed, the X axis of the charts represented time and could be accurately measured in inches. Initially, the X (time) and Y (speed) coordinates were determined for the leading edge of each road tube. Subsequent points between road tubes were then determined as required to adequately describe the curve. All data was recorded on the forms contained in Appendix E. The data was then key-punched for computer processing.

The computer program converting the speed-time data to speed-distance data was contained as an overlay on the OSU CDC 3600. The program accepted as input the time-speed data and output a tabular listing of speed vs. distance and time in 25-foot (8 m) increments. A typical output is contained in Figure 14. The algorithm to accomplish the conversion is contained in Appendix F.

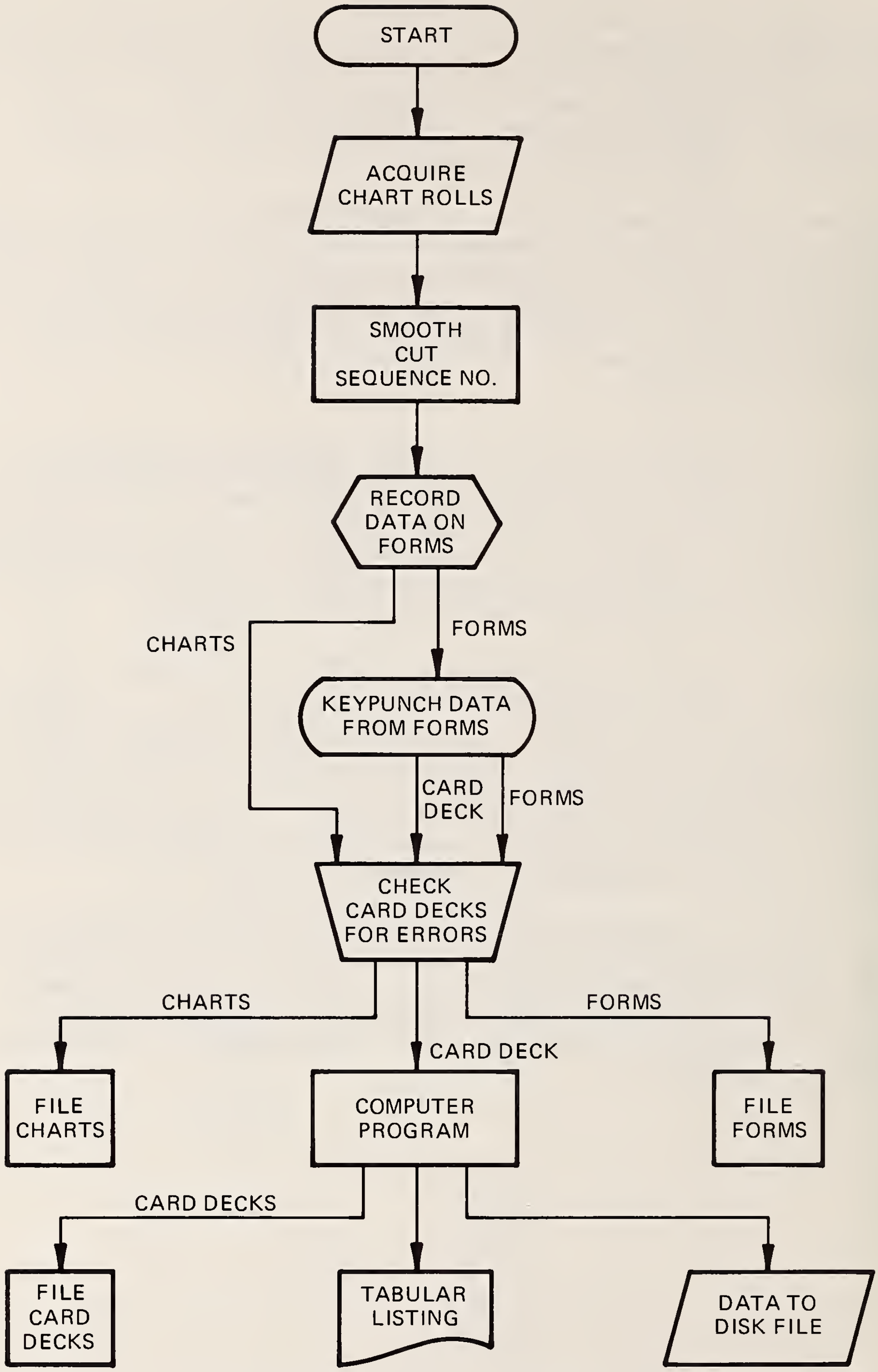


Figure 13. Manual Analog-Digital Conversion (Flow Diagram)

0123 07/25/74 CAR 04 RUN 06 FOG

DIST (FT)	SPEED (MPH)	TIME (SEC)	DIST (FT)	SPEED (MPH)	TIME (SEC)	DIST (FT)	SPEED (MPH)	TIME (SEC)
0	47.5	0	1000	46.3	13.91	2000	20.6	33.58
25	47.6	.35	1025	45.9	14.26	2025	19.1	34.46
50	47.7	.71	1050	45.5	14.62	2050	17.4	35.41
75	47.8	1.06	1075	45.0	14.98	2075	15.6	36.46
100	47.8	1.41	1100	44.6	15.34	2100	15.5	37.60
125	47.9	1.76	1125	44.1	15.71	2125	15.8	38.71
150	48.0	2.11	1150	43.7	16.08	2150	16.2	39.80
175	48.1	2.46	1175	43.2	16.46	2175	16.5	40.87
200	48.2	2.81	1200	42.8	16.84	2200	16.7	41.93
225	48.3	3.16	1225	42.4	17.22	2225	16.8	42.97
250	48.3	3.51	1250	42.0	17.61	2250	17.0	44.00
275	48.4	3.85	1275	41.6	18.00	2275	17.2	45.02
300	48.5	4.20	1300	41.3	18.40	2300	17.5	46.02
325	48.5	4.55	1325	40.9	18.80	2325	17.7	47.02
350	48.6	4.90	1350	40.5	19.20	2350	17.9	48.00
375	48.6	5.25	1375	40.1	19.62	2375	17.5	48.97
400	48.7	5.60	1400	39.7	20.05	2400	16.5	50.00
425	48.7	5.96	1425	39.3	20.48	2425	16.7	51.02
450	48.8	6.31	1450	38.9	20.91	2450	16.9	52.02
475	48.8	6.66	1475	38.4	21.35	2475	17.6	53.01
500	48.8	7.00	1500	38.0	21.80	2500	18.9	53.93
525	48.9	7.35	1525	37.5	22.28	2525	20.0	54.80
550	48.9	7.70	1550	36.9	22.76	2550	21.0	55.62
575	49.0	8.05	1575	36.3	23.25	2575	22.0	56.41
600	49.0	8.40	1600	35.8	23.75	2600	24.1	57.14
625	49.1	8.74	1625	34.5	24.26	2625	26.0	57.82
650	49.1	9.09	1650	32.5	24.80	2650	27.8	58.45
675	49.2	9.43	1675	31.9	25.34	2675	29.4	59.04
700	49.3	9.77	1700	31.4	25.89	2700	31.0	59.60
725	49.4	10.11	1725	30.8	26.45			
750	49.4	10.45	1750	30.2	27.02			
775	49.5	10.79	1775	29.6	27.61			
800	49.2	11.13	1800	29.0	28.20			
825	48.9	11.46	1825	28.6	28.78			
850	48.6	11.82	1850	26.9	29.38			
875	48.3	12.17	1875	26.2	30.01			
900	48.0	12.52	1900	25.5	30.65			
925	47.6	12.86	1925	24.8	31.32			
950	47.2	13.21	1950	24.0	32.00			
975	46.7	13.55	1975	22.0	32.76			

Figure 14. Typical Computer Output

PHASE II - EXPERIMENTAL RUNS

The second phase of this study consisted of the conduct of experiments. This section contains a description of the studies and their results.

Prior to the conduct of the studies, a number of pilot studies were conducted. The objective of these studies was in part to test the system and procedures under operating conditions and also to gain preliminary information required prior to the start of the actual runs. The most significant of these were speeds to be posted on the roads for normal driving under the no fog condition. To obtain such information, both volunteer and paid subjects were run under test conditions. Based on these studies, it was determined that 55 MPH (90 km/h) was an approximate speed to post. All individuals tested indicated that two runs were adequate to become familiar with the roads. It was also determined that six subject drivers was the optimum number to run per experimental session. This number permitted an adequate number of runs to be made for each subject within the operating schedule and kept the waiting time between runs to an acceptable level.

GENERAL PROCEDURES

Most of the experimental sessions were held during the late night and early morning hours. This time period was selected primarily for its weather conditions. This time period also enabled us to recruit subjects from the normal working sector of the population.

For each session, six subjects were randomly drawn from the subject pool. Each subject was contacted by telephone and scheduled for a particular morning. The subjects were furnished with a map to the test area by mail, with a reminder of the time and date for which they were scheduled.

As the subjects arrived at the test site, they were directed to the briefing area located in the trailer. When all were present, the subjects were given a 10 to 15 minute briefing during which the instructions contained in Appendix G were read to them. During the briefing, the subjects were shown a map of the area similar to that contained in Appendix B. The actual map used showed the main features of the roads and signing, but contained no references to the fog or data systems.

On the nights a test was scheduled, the experimenters were required to arrive at the test site two hours prior to the scheduled time to test and ready the equipment. Any malfunctions which had developed since the last test session were repaired, the fog system flushed, and the radars set up and calibrated.

To conduct the tests a minimum of three people were required. The Test Coordinator was located in the control center and directed the conduct of the test by two-way radio. The Coordinator was also responsible for monitoring the fog and data acquisition systems. A second individual was located at the trailer to maintain contact with and direct the test subjects. A third individual was required to obtain the visibility readings for each run. As pointed out earlier, wind shifts could cause the fog density to shift in a rapid and seemingly random manner. To compensate for this, the density readings were obtained for the north and south sections of the fog zone as soon as the vehicle had passed through a section. The control for the night targets was located in the center of the fog zone in front of the control building.

Subjects were run on the track one at a time with a car being started as soon as the previous vehicle had cleared the fog zone. The event bell located at the trailer was a signal to start another vehicle. Most subjects were given two familiarity runs on the test roads prior to the fog runs. An attempt was made to minimize the time lag between the last familiarity run and the first fog run to make the transition between the two as smooth and as unnoticeable as possible.

To obtain visibility information during the fog runs, the individual operating the targets turned on the north bank of lights and recorded the number visible as soon as a vehicle passed the controls. When the vehicle

cleared the fog zone, as indicated by the event bell at the control center, the south bank of lights were illuminated and the number visible was recorded. These two readings were used as a measure of visual range.

At the end of the last fog run, the subjects were directed back to the trailer for debriefing. This included the subjects filling out the Subject Data Forms contained in Appendix H and asking questions of the experimenter. Following the debriefing, the subjects were thanked for their participation, requested not to publicize the test, and dismissed. Following the dismissal, the system was secured and any malfunctions which developed during the tests repaired.

STUDY I - NORMAL DRIVING (NIGHT)

The normal driving study constitutes the basis upon which the remainder of the program was built. The major objective of this study was to determine which speeds drivers will normally drive under various conditions of reduced visibility.

Procedures

This study was conducted in nine experimental sessions from July 28 to August 9, 1974, between the hours of 2 a.m. and 5 a.m. All subjects were given a minimum of five fog runs (with the exception of one group when an equipment malfunction forced the cancelling of the test after the fourth run). However, if time and weather permitted, more than five runs were made. At the end of the last fog run, the subjects were directed back to the trailer for the debriefing.

Results

The results of this study consisted of the subjects' speed records for the familiarity and fog runs and their responses to the Subject Data Form.

Altogether, 51 subjects (there were a total of 3 no shows out of 54 scheduled) made a total of 102 clear and 291 fog runs. To determine the visibility conditions which existed for a particular subject on a particular run (since they could change from run to run) the north and south visibilities were obtained on each run and averaged. This average was taken as the basic measure. An additional restriction that the difference between the two not exceed 100 feet (30 m) was also placed on the data. The runs for which a delta of greater than 100 feet (30 m) existed were discarded.

The runs which were considered "good" were grouped into four visibility groupings: 100-, 200-, 300-, and 400-foot (30, 60, 90, and 120 m) visibility. The 100-foot (30m) visibility group consisted of the runs on which an average visibility was between 50 and 149 (15 and 45m); the 200-foot (60 m) group the runs with an average visibility between 150 and 249 (45 m and 75 m); etc. These groupings formed the independent variable for the study.

Of the 291 fog runs completed during the course of the study, 50 (17%) resulted in visibility differences between the north and south sections greater than 100 feet (30 m) and were discarded. Of the remaining 241 runs, four were deleted during analysis as being unreliable (due to radar dropouts or equipment failures) leaving a total 237 runs made by 51 subjects. Each run considered reliable was classified into one of four visibility categories as outlined above. However, since a given driver could experience a particular visibility condition on more than one run, the measures within a visibility classification were not independent.

Consequently, the multiple runs for a given driver within a visibility category were averaged to achieve independent measures. As a result of this process, the total sample size was reduced to 92 independent runs. The distribution summaries are contained in Table 1.

Table 1. Frequency Distributions of Runs by Visibility Conditions

DISTRIBUTION OF RUNS	
50 - 149 feet (15- 45m)	20
150 - 249 feet (46- 75m)	34
250 - 349 feet (76-106m)	27
350 - 449 feet (107-137m)	11
TOTAL	92

The speed-time charts for the clear and fog runs were reduced according to the procedures outlines above. The analysis of the data consisted of computing the 15th, 50th, and 85th percentile speeds at each position indicator. The results of this analysis are contained in Figures 15 through 21. Figures 15 through 17 show the comparisons of the same percentile curve for the familiarity runs and each visibility condition. Figures 18 through 21 show a comparison of the three percentile curves for the separate visibility conditions.

In the figures the ordinate represents speed and the abscissa represents road position shown both in terms of cumulative distance from the beginning of the speed monitoring area and with respect to the location of the position indicator tubes (Appendix B). The first position indicator was at the start of the signing zone (zero cumulative distance) and the last 300 feet (90 m) south of (beyond) the fog zone (2700 feet (825 m) cumulative distance). The fog zone extended from just after position indicator 6 to position indicator 13.

An inspection of these figures indicates a fairly stable pattern of driver responses in terms of five zones within the test track. For the clear runs, the speeds were fairly uniform with a gradual slowing for the curve at the end of "B" Street. The fog runs showed a similar pattern existed from position indicators 1 to 4; the drivers showed a fairly constant speed although some acceleration was detected. Between indicators 4 and 6, however, an initial deceleration zone was apparent, followed by a sharp deceleration zone up to about indicator 9. The speed curves were

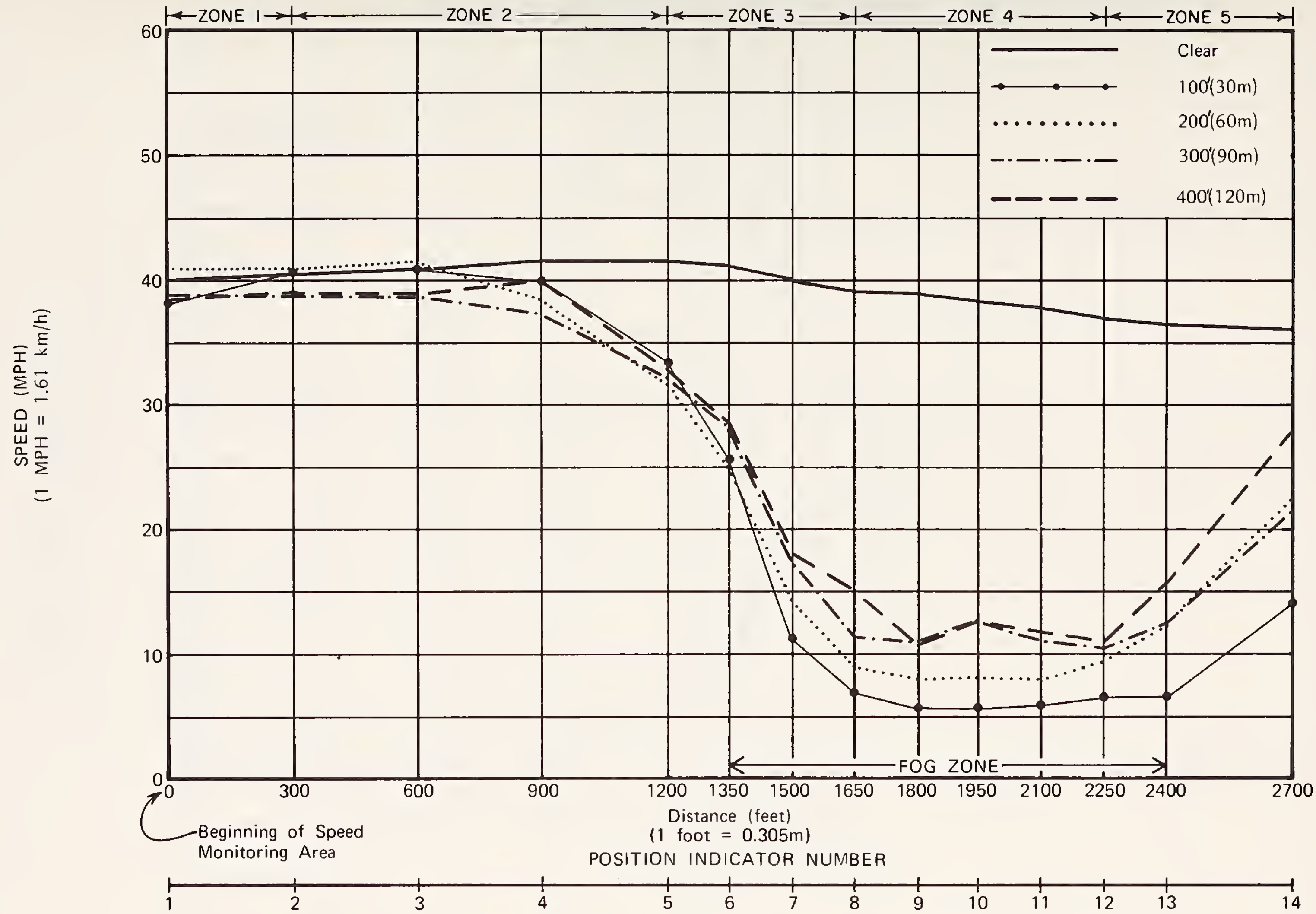


Figure 15. Fifteenth Percentile Curves - Study I

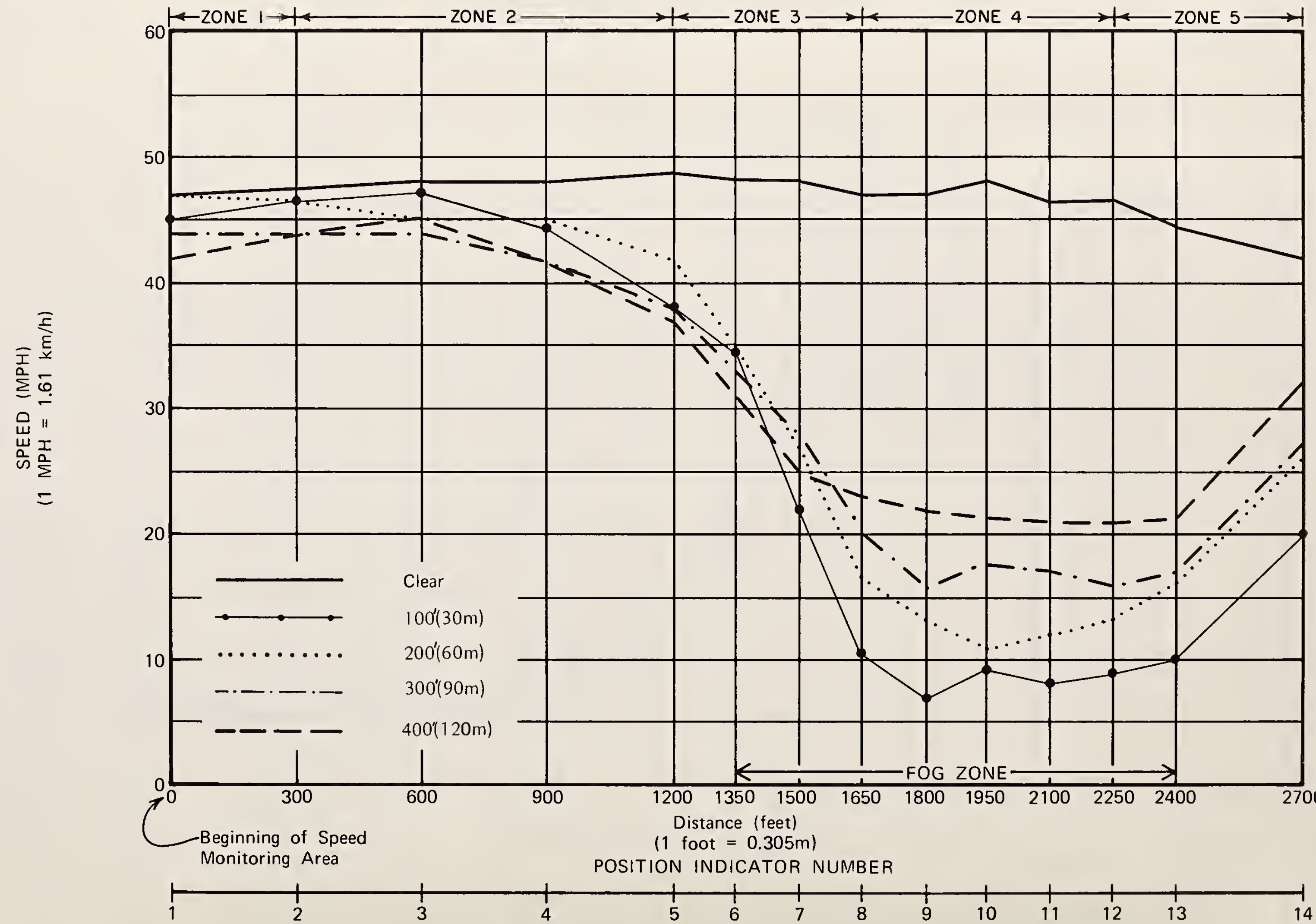


Figure 16. Fiftieth Percentile Curves - Study I

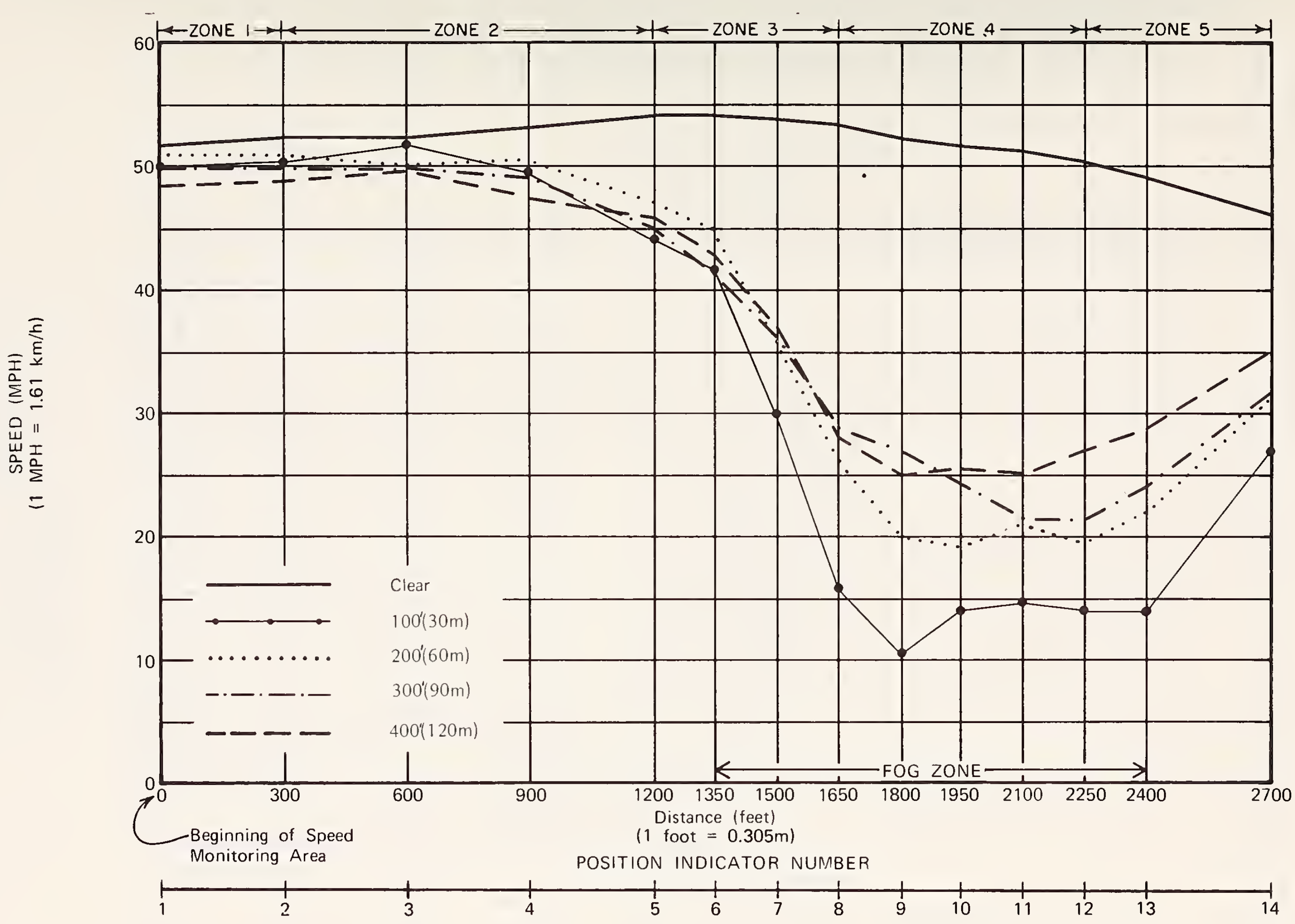


Figure 17. Eighty-fifth Percentile Curves - Study I

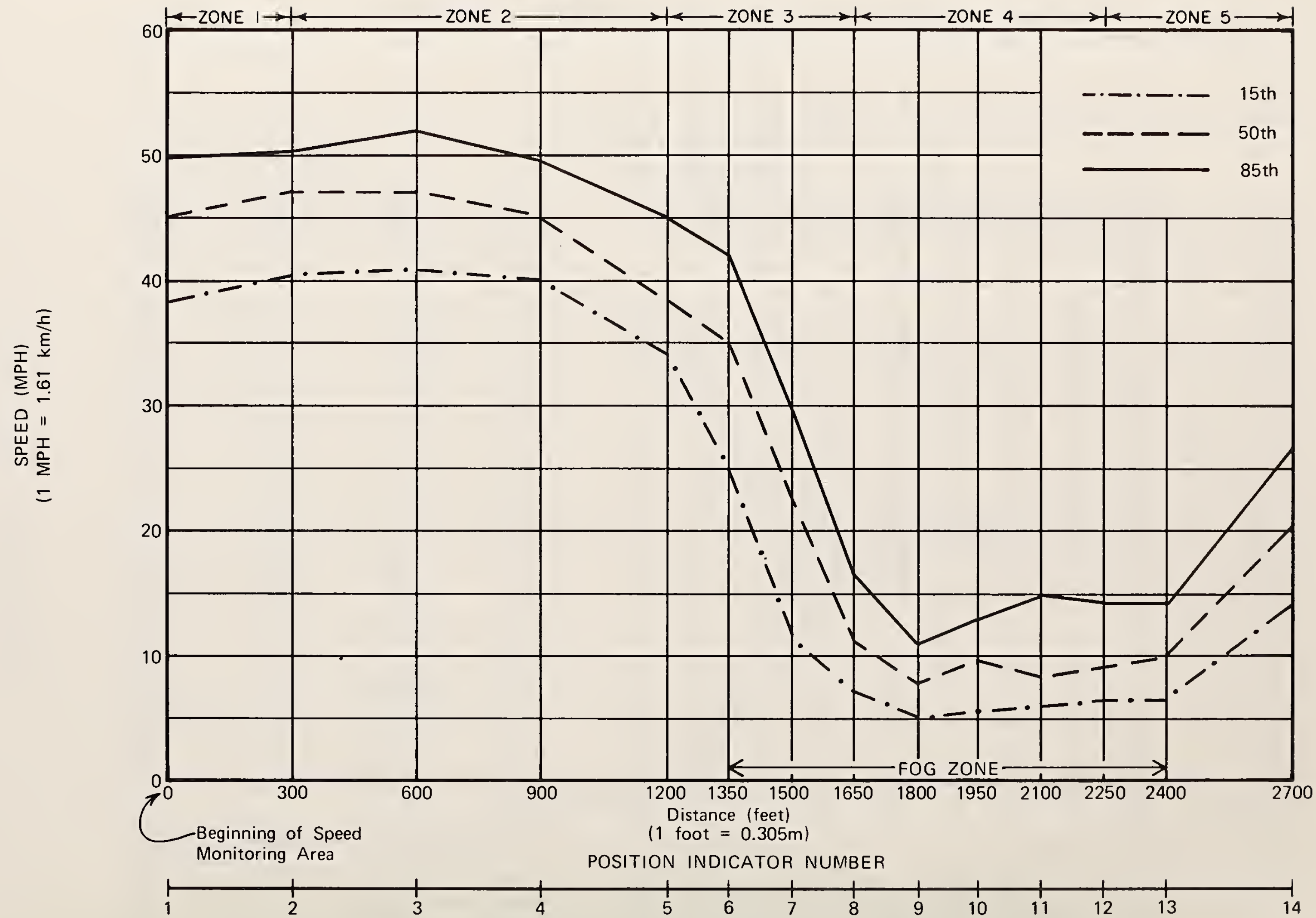


Figure 18. Percentile Curves, 100-Feet Visibility - Study I

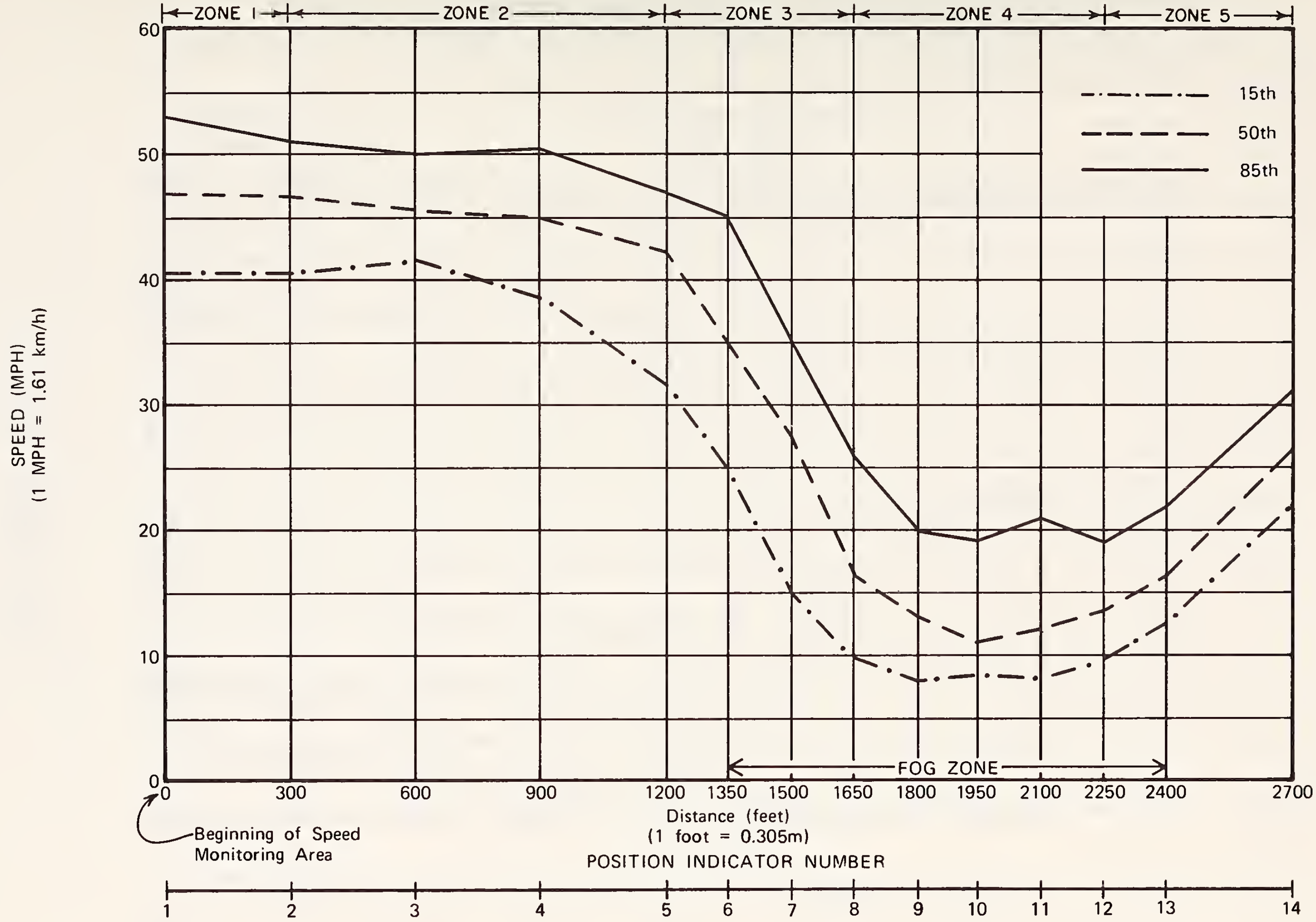


Figure 19. Percentile Curves, 200-Feet Visibility - Study I

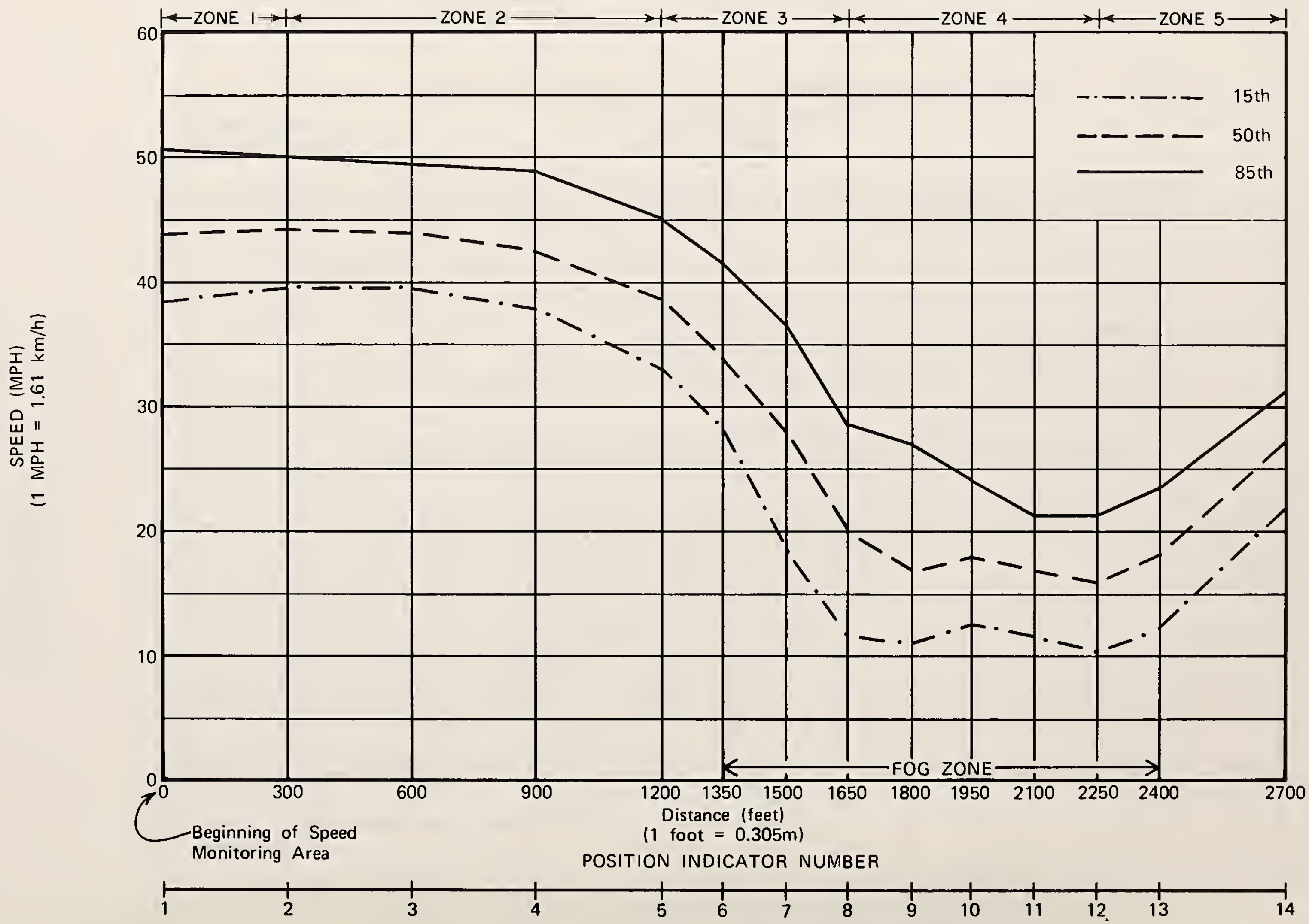


Figure 20. Percentile Curves, 300-Feet Visibility - Study I

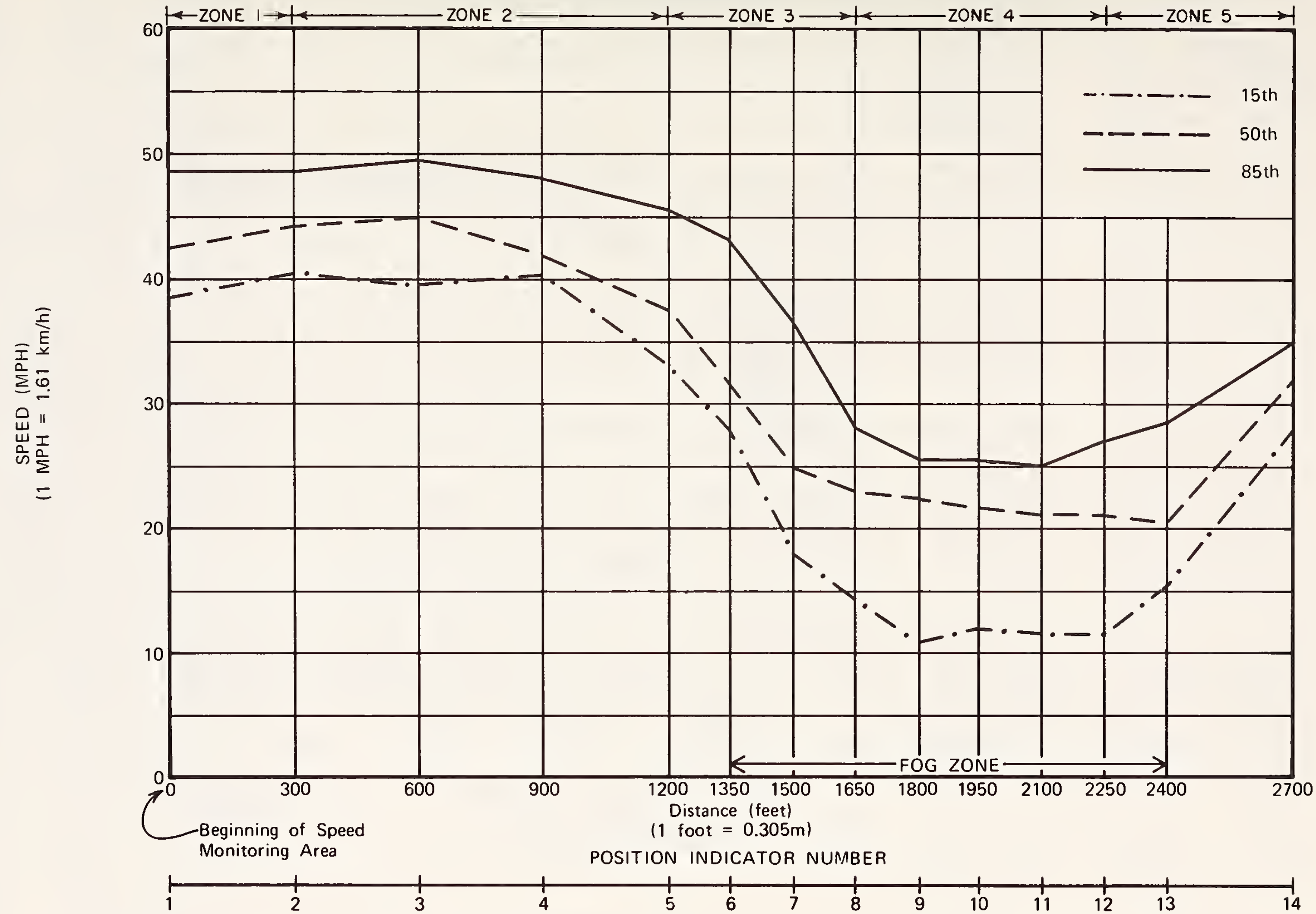


Figure 21. Percentile Curves, 400-Feet Visibility - Study I

then relatively flat through the fog from indicators 9 to 13 after which there was an acceleration. An inspection of Figures 18 through 21 indicates that there was an approximate five miles per hour (8 km/h) difference between each of the 3 percentile curves within each visibility condition. In addition, the respective percentile curves also differed by approximately five miles per hour (8 km/h) between the 100-, 200-, and 300-foot (30, 60, and 90 m) visibilities (see Figures 15 through 17). Very little difference was seen between the 300- and 400-foot (90 and 125 m) conditions.

In order to obtain a value to be used as a posted speed prior to the fog in Study II, the median value through the fog zone for each percentile curve for each visibility condition was calculated. The median values were rounded to the nearest 5 MPH (8 km/h) speed. These values are contained in Table 2.

Table 2. Median Percentile Speeds Through Fog Zone

MEDIAN PERCENTILE SPEED (mph) (1 MPH = 1.61 km/h)	VISUAL RANGE (feet)			
	100' (30m)	200' (60m)	300' (90m)	400' (120m)
15th	5	10	10	10
50th	10	15	20	20
85th	15	20	25	25

To provide an estimate of the variability of fog conditions, the mean speeds, standard deviations, and coefficients of variation were calculated for each position indicator. These data are contained in Figure 22. The coefficient of variation is a composite measure (ratio of the standard deviation to the mean multiplied by 100) which permits comparison of standard deviations which have different means. This measure of relative variability can be interpreted as an inverse measure of traffic flow with lower values indicating a more uniform or smoother traffic flow.

The mean speeds followed a pattern similar to the percentile speeds in terms of driver behavior in each of the five zones mentioned above. The standard deviations followed a slightly different pattern. They tended to be fairly stable from position indicators 1 to 4, then increased

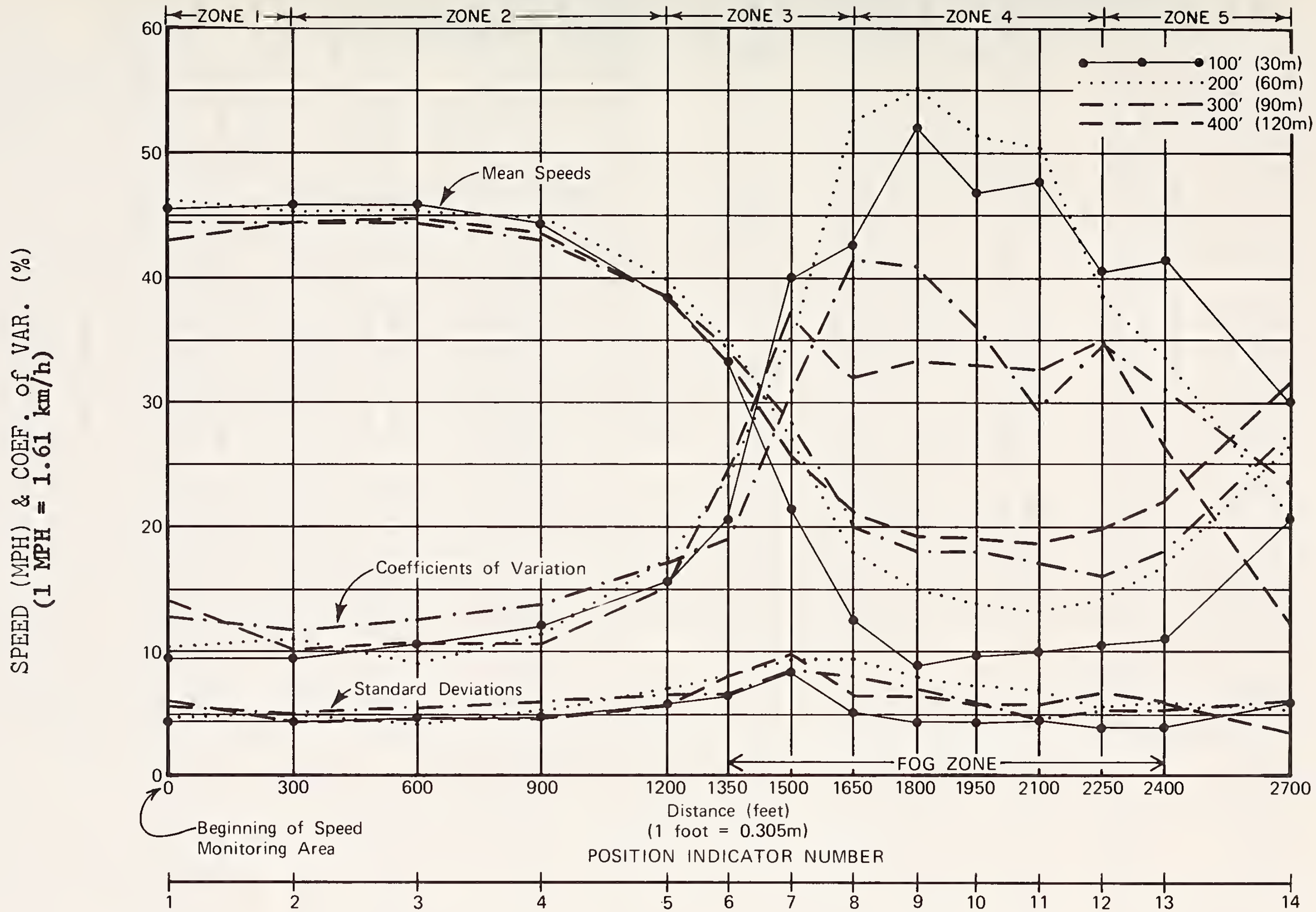


Figure 22. Mean Speeds, Coefficients of Variation and Standard Deviations - Study I

to a peak at position indicator 7, and then decreased through the fog zone. Little difference between the standard deviations for the four fog conditions was apparent up to position indicator 7. After position indicator 7, the standard deviation for the four conditions tended to separate with the 100-foot (30 m) visibility condition having the smallest values. The 200-foot (60 m) condition tended to result in the highest levels of variability with little difference between the 300- and 400-foot (90 and 120 m) conditions.

The coefficients of variation are predominantly influenced by the mean speeds. In general, an inverse relationship exists between the two sets of curves in each of the above-mentioned zones. The 200-foot (60 m) condition tended to have the highest relative variability followed by the 100-, 300-, and 400-foot (30, 90 and 120 m) conditions. It will be noted that while the 100-foot (30 m) condition had the smallest absolute variability it tended to have the second highest relative variability. This condition is accounted for by the lower mean speeds for the 200-foot (60m) condition.

An analysis of the data was also performed to determine if a subject's mean speed changed with repeated exposures to a given density of fog. This analysis showed that there was no significant difference at the 95 percent confidence level.

The results of the subject data forms are contained in Appendix I. With respect to Appendix I, of the 51 subjects who participated in this study, 23 were males and 28 were females. Their ages ranged from 16 years to 59 years with the average being 34 years. The subjects' average driving experience was 16.5 years with an average of 9,300 miles (15,000 km) driven per year. Forty-five of the subjects reported having no prior knowledge concerning the study, while six did admit they had some knowledge. The subjects reported that in good weather, most felt they drove at or under the speed limit. Little change in speed was seen in highways such as 99W as a result of the new 55 MPH (90 km/h) fuel conservation maximum speed limit. A reduction in speed of about ten miles per hour (15 km/h) was reported for interstates as a result of the speed reduction.

The drivers reported that they would have driven at a substantially reduced speed if they encountered the same fog conditions, either on interstate or rural highways, as encountered during the tests. Since the subjects may have experienced different visibilities on different runs, the predominant visibility during a test session was used as the basis for clarifying the subjects' response for this and subsequent questions where separate visibilities are shown. The speeds reported for rural highways were on average of three miles per hour (5 km/h) lower than those reported for interstate. The reported speeds tended to increase with increases in visibility, ranging from an average of 13.75 MPH (22.1 km/h) for the 100-foot (30 m) visibility to 32.27 MPH (51.9 km/h) for 400-foot (120 m) visibility on the interstates. On rural highways, these values ranged from 12.81 to 28.28 MPH (20.6 to 45.4 km/h). It should be noted that some drivers indicated a zero speed, implying that they would stop.

In terms of their driving, all subjects felt that they were given adequate exposure to the roads to become familiar with them prior to the fog. Forty-four of the subjects (86%) felt they did not drive any more cautiously during the test runs than they would have if they had been on a highway.

Concerning their previous experience in driving in fog, all subjects had some exposure and were evenly split between once or twice per year to eight to ten times per year. Most of their experience had been on rural highways or interstates. A few experienced fog in residential areas. The tactics the drivers reported they usually used were to drive slower in the right lane and follow either another vehicle or pavement stripes.

The drivers' reactions to the fog the first time they encountered it were separated into emotional type of responses and driving reactions. A range of emotional responses was reported, with surprise being the most frequent. In terms of the driver reaction, most drivers reported slowing down. The majority reported that these reactions occurred either just before or just after entering the fog. The majority also indicated that their reactions were the same after repeated exposures to the fog but they became less intense. The majority (86%) reported more confidence as the number of runs increased.

Most drivers reported driving in the right lane at estimated speeds from approximately 10 to 18 MPH (16 to 29 km/h). These estimates are in agreement with the actual speeds recorded (50th percentile speeds Figures 16 and 18 through 21).

Most drivers reported using and preferring low beams while in the fog. The drivers reported that the fog was patchy on about 45 percent of the runs. Almost all drivers indicated that they tended to speed up in clear areas.

In terms of the speeds the drivers considered safe for the conditions they encountered, very little difference existed between the estimates for the test track and rural highways such as 99W. The speed estimates for the interstate were somewhat higher. Again, the estimates for the test track were in agreement with the median speeds actually recorded.

The drivers' estimates of visual range were quite a bit lower than those reported by the experimenters. This was due in most part to the lack of objects for the drivers to sight on and the back-scatter from their headlights.

STUDY II - POSTED SPEED

The second study was in reality an extension of the first. The primary objective of this study was to determine which of the percentile speeds, if any, from the first would result in the smoothest traffic flow when used as a posted speed. A secondary objective was to determine the location of the greatest turbulance (the location of the greatest variability in the traffic flow) with respect to the fog bank.

Procedures

The general procedures for this second study were identical to the first with the following exception:

A variable message speed sign was installed 500 feet (150 m) in advance of the leading edge of the fog zone. This sign was a standard black on white 55 MPH (90 km/h) sign which was modified to accept riders which would change the speeds displayed from 5 to 25 MPH (8 to 40 km/h) in five miles per hour (8 km/h) increments. During the familiarity runs, the 55 MPH (90 km/h) speed was displayed. During the fog runs, the speed displayed on the sign was determined for each run. To accomplish this, the visibility existing on the road was determined at the time a vehicle left the starting point. This information was radioed to the test coordinator who determined the visibility category existing on the road and selected the speed that should be displayed (Table 2). The test coordinator then radioed the information to an individual located at the speed sign who changed the displayed speed. The visibilities were again determined after the vehicle had passed through the fog zone and recorded.

The subject instruction for Study II and the Subject Data Form are contained in Appendixes G and H. Both were modified from Study I.

Results

As with the previous study, the results of this study consisted of the drivers' speed records for both the familiarity and fog runs. One hundred five subjects made a total of 210 clear runs and 530 fog runs. Again, the visibilities for the north and south sections of the fog zone were averaged and runs with a differential greater than 100 feet (30 m) were eliminated (178 runs) as were the runs which could not be reliably smoothed (21 runs). For this study, a further restriction existed in that the speed which was posted may or may not have been accurate for the fog conditions the driver encountered on any particular run. These conditions resulted from a change in fog density between when the sign was posted and when the vehicle passed through the area. These runs (62 runs) were eliminated from the analysis resulting in 269 runs. The multiple runs for individual drivers within a visibility-posted speed condition were averaged resulting in a sample size of 140 independent runs. The distribution of runs by visibilities and percentiles is contained in Table 3.

Table 3. Frequency Distribution of Runs by Visual Condition and Posted Speed

Posted Speeds (Percentiles)	Visual Conditions (feet) (1 foot = 0.305m) 100	200	300	400
15th	8	17	11	3
50th	13	11	16	2
85th	11	24	17	7

The speed-time charts were reduced according to the procedures outlined above. The analysis of the data consisted of computing mean speed, standard deviation, coefficient of variation, and the 15th, 50th, and 85th percentile speeds at each position indicator. This analysis was conducted for both the clear runs and fog runs. However, since the 400-foot (120 m) condition had an unreliable sample size and the differences between the 300- and 400-foot (90 and 120 m) conditions were not significant (the posted speeds were the same), the two were combined resulting in nine visibility-posted speed combinations.

The curves for the means, standard deviations and coefficients of variation for the clear runs are contained in Figure 23. This data showed a small amount of acceleration up to approximately position indicator 6, some deceleration through the fog zone, followed by a gradual deceleration in preparation for the curve at the end of the track. The standard deviations and coefficients of variation were fairly uniform over the entire length of the speed monitoring area.

Similar data for the three posted speed conditions within each of the three visibilities are contained in Figures 24 through 26. An analysis was also made of the 15th, 50th, and 85th percentile curves within each of the nine posted speed-visibility conditions. However, the data was almost identical to the mean speeds in terms of the trends in the data and consequently is not presented here.

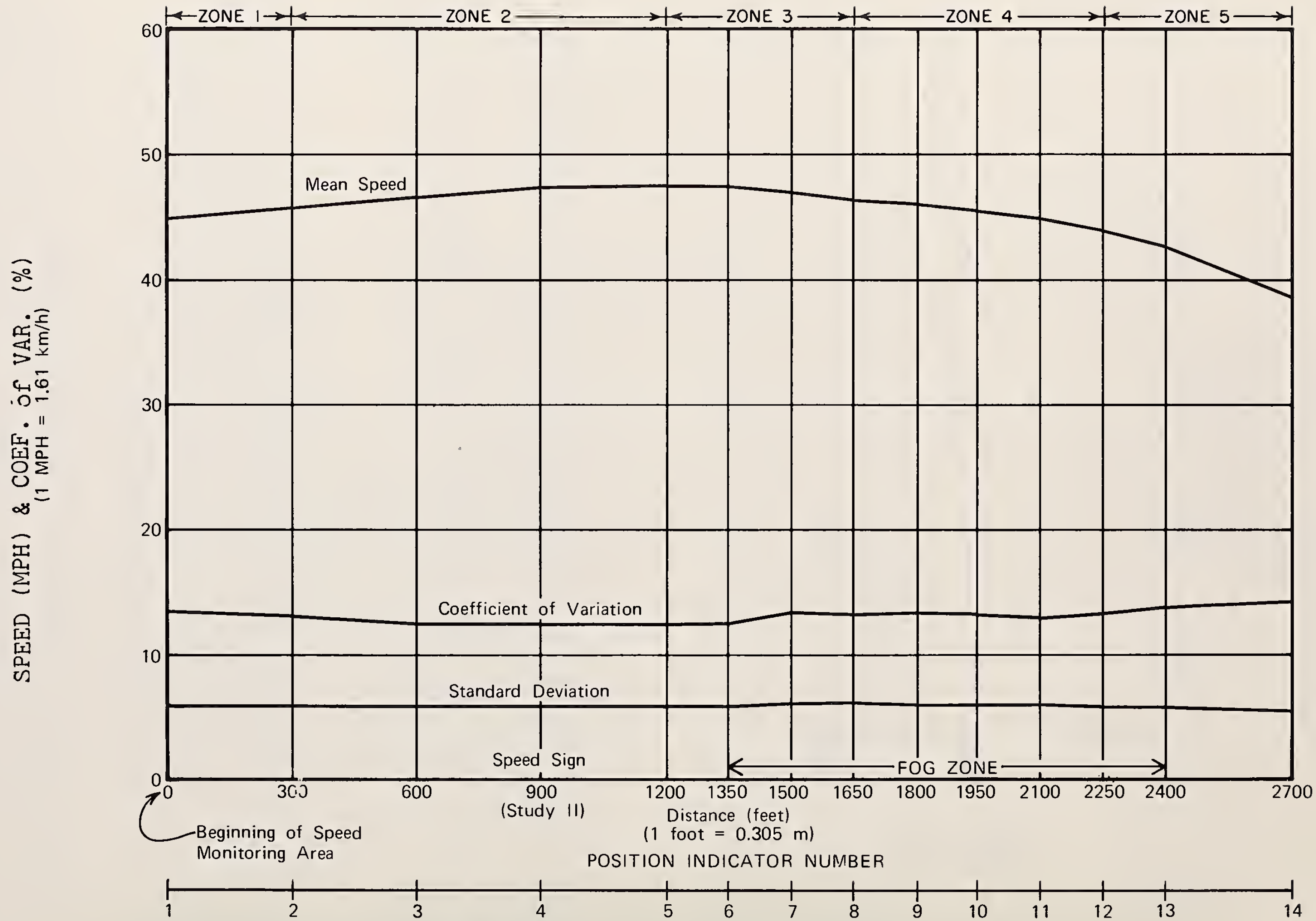


Figure 23. Mean Speeds, Coefficients of Variation and Standard Deviations for Clear Runs - Study II

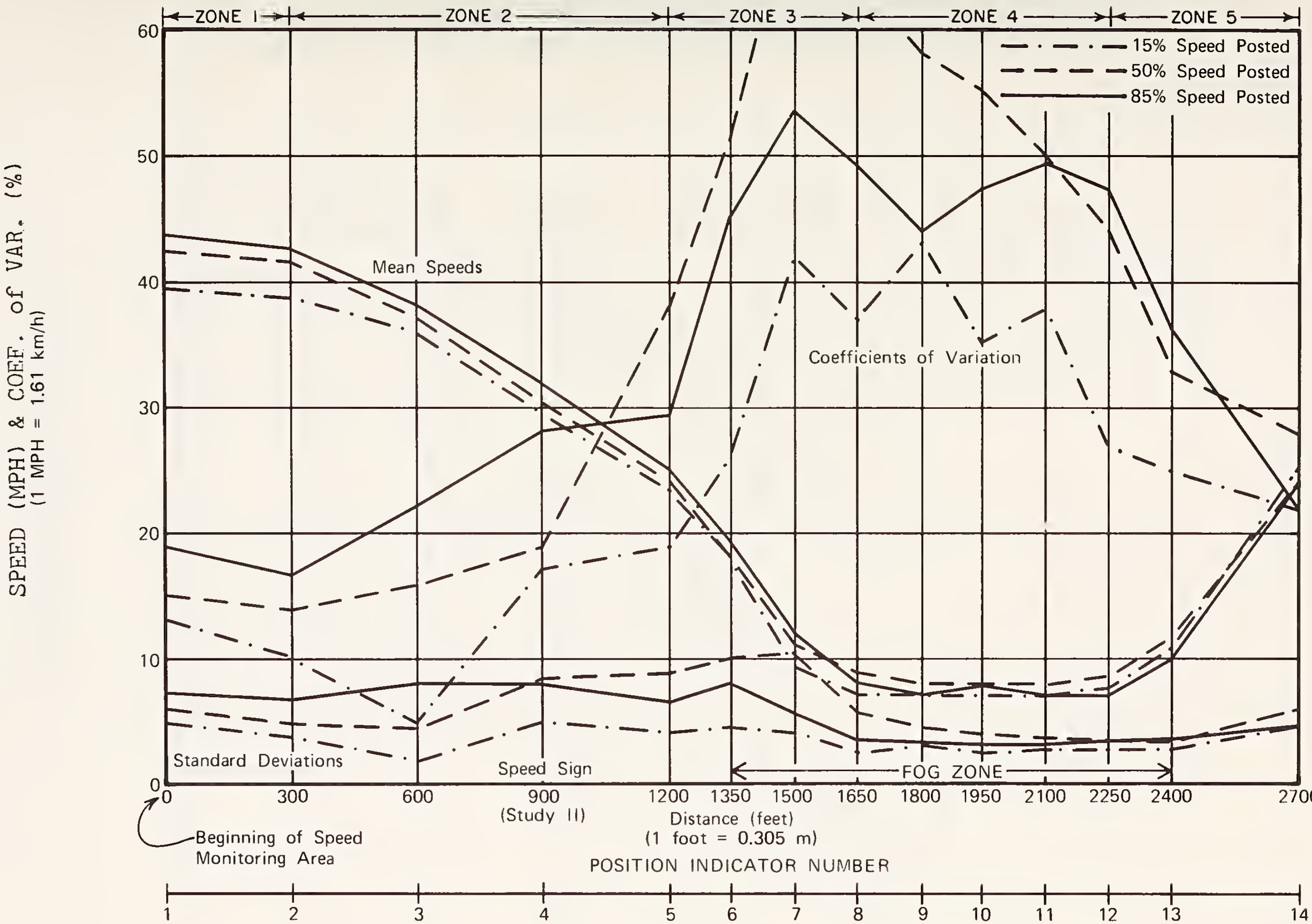


Figure 24. Mean Speeds, Coefficients of Variation and Standard Deviations for 100-Feet Visibility - Study II

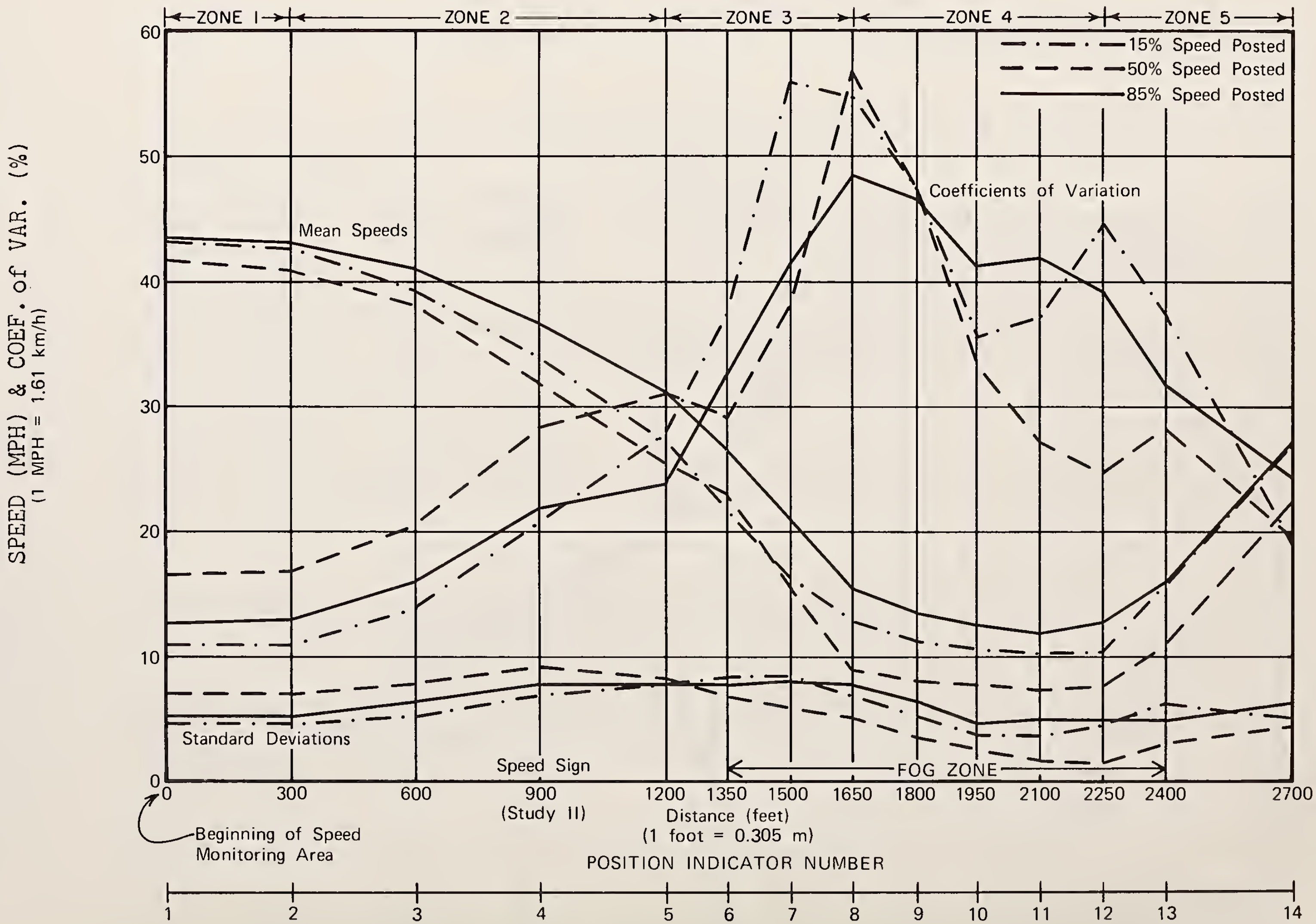


Figure 25. Mean Speeds, Coefficients of Variation and Standard Deviations for 200-Feet Visibility - Study II

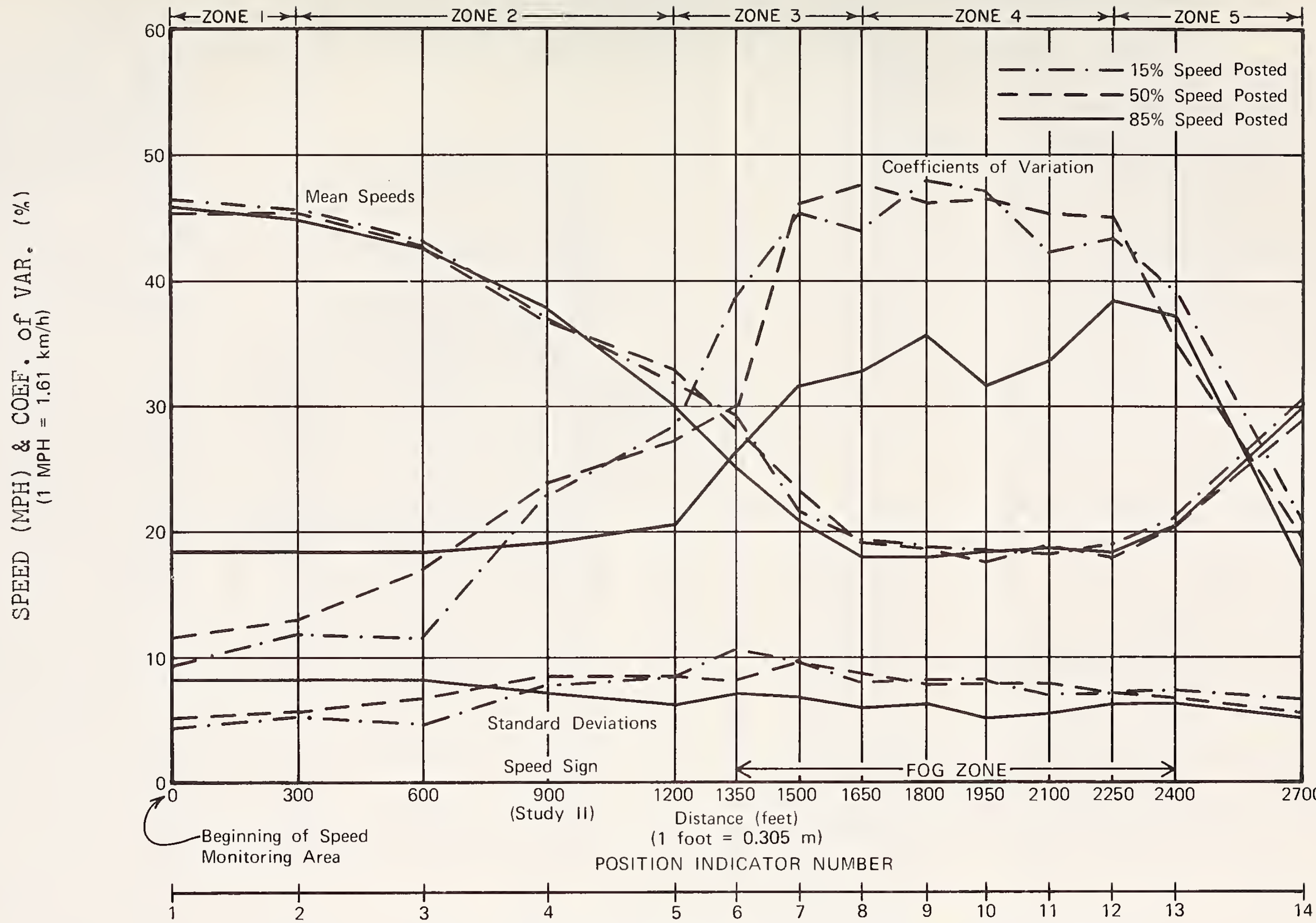


Figure 26. Mean Speeds, Coefficients of Variation and Standard Deviations for Combined 300 and 400-Feet Visibilities Study II

With respect to the data in Figures 24 through 26, two general comparisons concerning the effects of the variable speed sign were made; comparisons between this data and the Study I data (no speed sign) and comparisons between the conditions within Study II.

A comparison of the curves between Study I and Study II indicated that the presence of the speed sign had some effect upon the driver's behavior. In general, the speed sign appeared to have smoothed out the mean speed curves by making the deceleration start earlier and become more gradual. In the Study II curves, zones 1, 2 and 3 are less well defined. It may be that the sign has in essence added an additional zone which has the effect of reducing zone 1 and smoothing zones 2 and 3. It also appears that the observed speeds were somewhat lower in Study II than Study I. Figure 27 shows this comparison. It should be noted that this curve was included only to illustrate the difference; it is not the curve used in the analysis.

To provide a direct comparison of the effects of posting different percentile speeds upon driver behavior in the fog zone, the mean speeds for each of the nine posted speed visibility conditions are contained in Table 4. To arrive at these values, the average speed through the fog was calculated for each subject.

Table 4. Mean Speeds Through Fog Zone - MPH (km/h)

Posted Speeds (Percentiles)	Visibility Conditions (feet): 100' (30m)	200' (60m)	300'-400' (90m-120m)	Row Means
15th	9.5 (15.3)	13.8 (22.2)	19.4 (31.2)	14.2 (22.9)
50th	11.1 (17.9)	11.6 (18.7)	19.5 (31.4)	14.1 (22.7)
85th	9.4 (15.1)	16.4 (26.4)	19.3 (31.1)	15.0 (24.2)
Col. Means	10.0 (16.1)	13.9 (22.4)	19.4 (31.2)	

The Analysis of Variance summary for this data is continued in Table 5 An inspection of Table 4 indicates that posting the different percentile speeds had little or no effect upon the drivers' behavior in terms of their mean speeds. The visibility conditions, however, did have an effect with the lower visibility conditions resulting in lower speeds. These findings are confirmed by the analysis of variance conducted on the data. The posted speed conditions were not significantly different while the visibility conditions were significantly different beyond the .01 level of confidence.

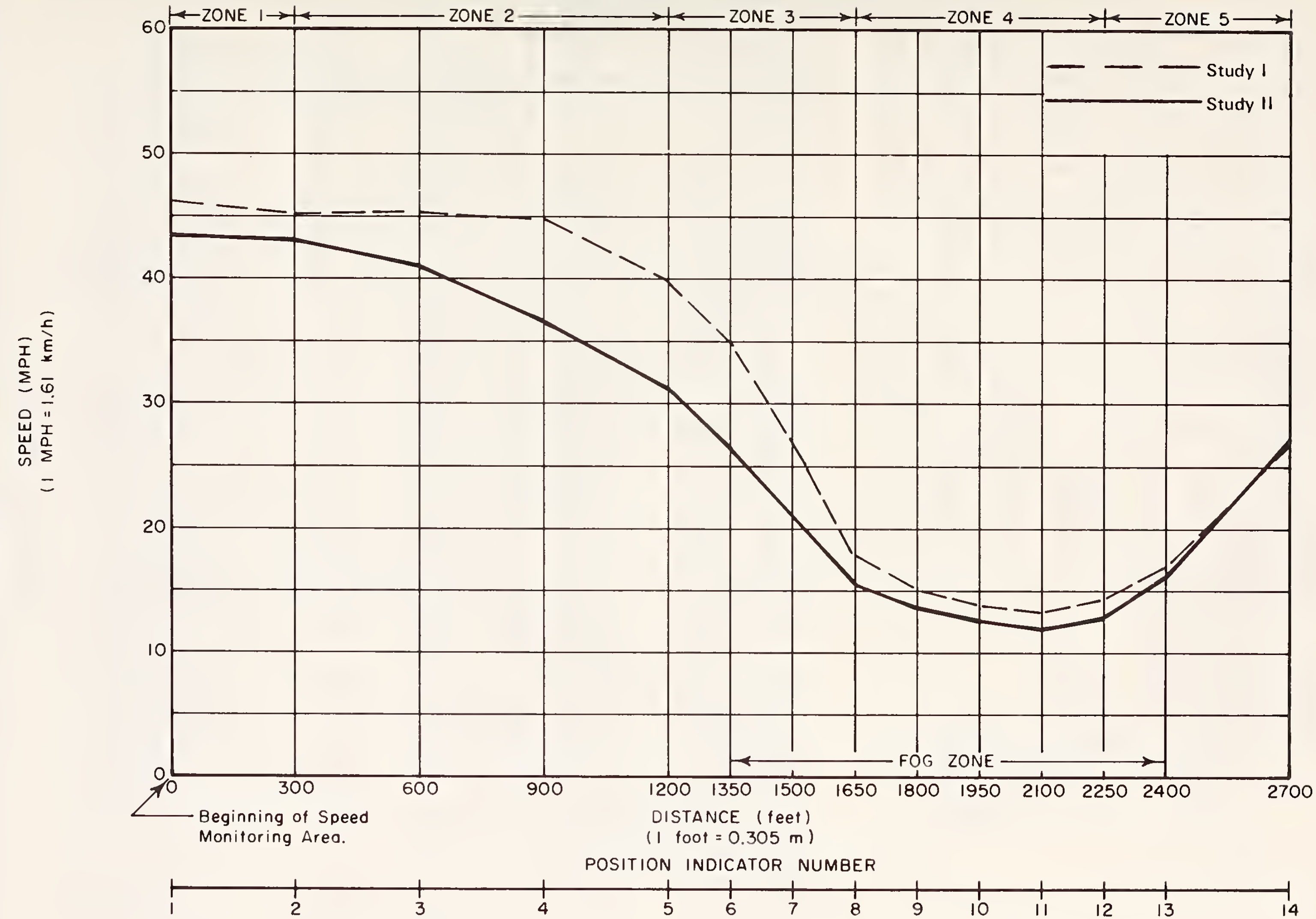


Figure 27. Comparison of Mean Speed Curves Between Study I and Study II

Table 5. Analysis of Variance Summary of Mean Speeds Through Fog Zones

Source of Variation	SS	df	MS	F
Posted Speeds	24.43	2	12.21	
Visual Conditions	1921.3	2	960.7	29.5**
Interaction	11.7	4	2.9	
Within Cell	4266.9	131	32.57	

Although not presented here, an analysis conducted on each of the three percentile speeds (15th, 50th and 85th percentiles) within each of the nine posted speed-visibility cells showed a similar lack of effect; posting the 15th percentile speed did not slow down the faster drivers nor did posting the 85th percentile speed speed-up the slower drivers.

In terms of standard deviations, the effect of posting the various percentile speeds was evident. Figure 28 shows that there is a relationship between visibility and the optimum speed for stability. At extremely low visibility levels (below 100 feet (30 m)), posting either the 50th or 85th percentile speed produced higher values in terms of standard deviations, thus produced less stable flow. At the 200 foot (60 m) visibility level, posting the 50th percentile speed produced the most stable flow in the fog and at the combined 300-400 foot (90-120 m) level, posting the 85th percentile speed resulted in the most stable flow.

The coefficients of variations for the three visibility conditions were plotted in an attempt to directly compare our findings with those of Stephens[1].

The coefficients of variation for the three visibility conditions showed apparent differences both prior to and within the fog zone. The 100-foot (30 m) visibility condition tended to be the most erratic both in terms of the values observed and the shape of the curves, while the 300 to 400-foot (90-120 m) conditions tended to be the most systematic. In all three cases, the values observed in Study II tended to be higher than for Study I.

1. Stephens, B.W.; Some Principles for Communication With Drivers Through the Use of Variable-Message Displays; Special Report 129 Highway Research Board, July 1971.

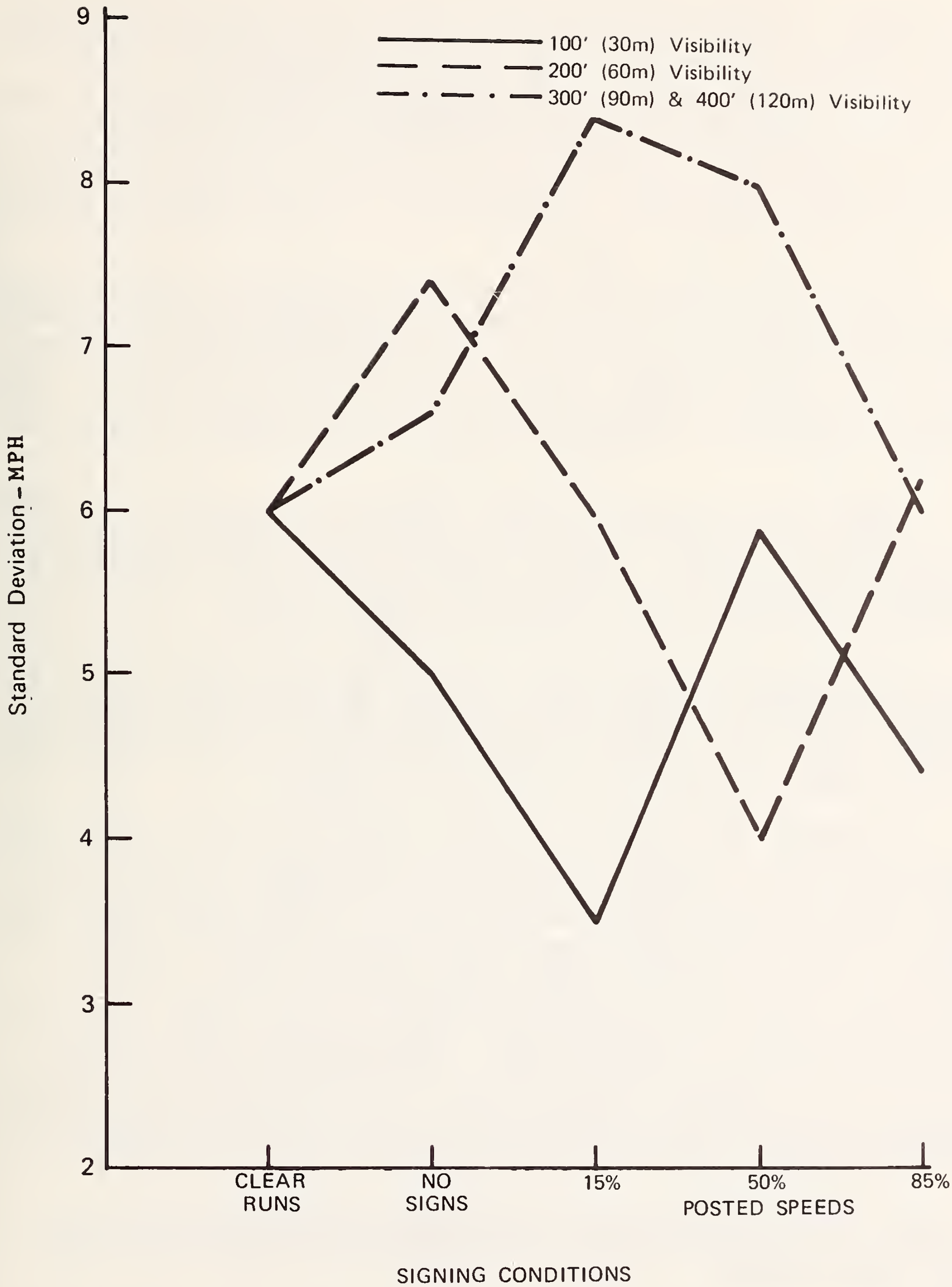


Figure 28. Mean Standard Deviations Through tne Fog Zone for the Signing Conditions of Study I and Study II

Figure 29 contains the mean coefficients of variation for the various conditions. As can be seen, the clear runs, which represent a base line data, resulted in an average coefficient of approximately 13. The presence of the fog (Study I, no speed signs) resulted in a sharp increase in the coefficient of variation with the 200-foot (60 m) visibility condition resulting in the highest values followed closely by the 100-foot (30 m) condition. The combined 300 to 400-foot (90 to 120 m) condition exhibited the lowest values. The addition of a posted speed sign resulted in higher coefficients of variation.

When the posted speed which resulted in the greatest stability (lowest coefficient of variation) was plotted against visibility, it too showed that the percentile speed which produced the greatest stability at one visibility level would not produce the best stability for the other levels. It should be noted, however, that in all cases the coefficient of variations exceed the coefficients that were observed when no signs were posted.

In most part, our findings agree with those of Stephens in that there is an optimum posted speed for each visibility condition which will result in the optimum stability. However, our study shows that in extremely low visibility ranges, the posted speed that produced the most stable traffic flow was significantly lower than the prevailing speeds.

A comparison of Stephens' data and data from this study may hold the key to the apparent contradiction. Stephens reported coeefficients of variation between 0.11 and 0.15 with speed in the 40 to 50 MPH (60 to 80 km/h) range. The coefficients of variation in our study ranged 0.25 to 0.70 with speeds between 9 and 20 MPH (14 to 32 km/h).

In comparing one specific visibility range, 1 to 100 feet (0 to 30 m) from Stephens and 100 feet (30 m) from our study, the differences become much more apparent. Stephens reported the optimum posted speed to be approximately 40 MPH (60 km/h) which, according to statements made in his report, implies that the nonsigned "natural speeds" of the vehicles through the fog was slightly higher than 40 MPH (65 km/h). Our data showed that posting the 15th percentile speed, 5 MPH (8 km/h), produced most stable traffic flow through the fog with the mean speed of the subjects recorded at 10 MPH (16 km/h). This indicates that the actual visibilities may have differed greatly. We know, from personally driving the test track under fog conditions, that it is practically impossible to maintain a speed in excess of 20 MPH (32 km/h) in what we called 100-foot (30 m) visibility.

The results of the Study II Subject Data Forms are contained in Appendix I. Of the 105 subjects who participated in Study II, 44 were males and 61 females.

The subjects' responses as to what they considered to be the greatest hazard while driving in fog were the same for both interstates and rural highways. The subjects felt that running into a stationary object or

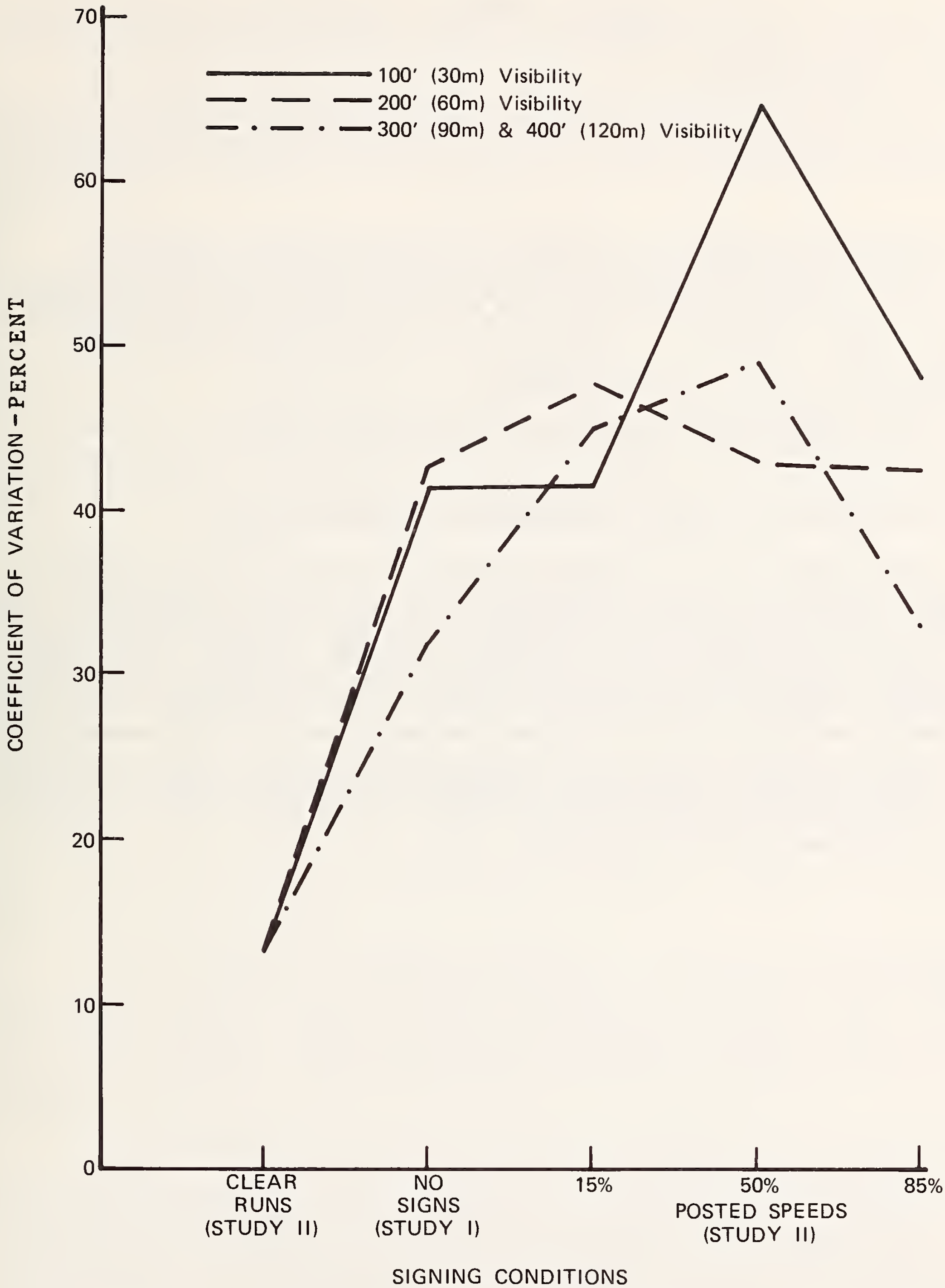


Figure 29. Mean Coefficients of Variation Through the Fog Zone for the Signing Conditions of Study I and Study II

vehicle on the road was the most hazardous situation followed by running off the road, being overtaken by a faster vehicle, and overtaking a slower moving vehicle.

Seventy-seven subjects (73%) reported they did not drive more cautiously during test runs. For the 26 who did, the usual reason given was thay they knew it was a test situation.

Eighty-one percent of the subjects stated that they usually attempted to slow down at the posted speed sign; however, only 25% indicated that they attempted to drive at the posted speed through the fog. For those who did not the most typical reason given was that they drove slower. However, 12 subjects (21%) indicated that they were watching the road, not the speedometer.

Most subjects had experienced driving in fog prior to the tests. Most of the subjects' experience was on interstate and rural roads. The tactics usually used included slowing down, staying in the right lane, and following another vehicle or watching the pavement stripes.

The majority of the drivers indicated that they had some difficulty maintaining their lateral position on the road. Most indicated they tended to be left of where they thought they were. This difficulty tended to occur in the middle of the fog zone. As with the first study, most subjects reported they became more confident as the number of trials increased, with the reason being that they became more familiar with the situation and the road. The drivers' estimates of what they considered to be safe speeds for fog conditions they encountered on this set of roads and their estimates of what they thought would be a safe speed for interstates such as I-5 and rural highways such as 99W follow patterns similar to those found in the first study.

STUDY III - INFORMATION-HAZARD STUDY

The purpose of the Information-Hazard Study was to determine driver response to various highway hazards which may be encountered under conditions of reduced visibility.

Procedures

The design for this study was a 2 x 3 x 4 factorial design with two levels of information, three levels of visibility and four levels of hazards. The two levels of information used in the study were:

Level I - Flashing Speed: This condition consisted of an internally illuminated, variable message sign. The speed values posted were the speeds identified in Study II as resulting in best traffic flow in terms of speed variability.

Level II - Flashing Speed Plus Hazard Type: Similar to Level I, but with the nature of the hazard added to the sign.

The three visibility conditions consisted of 100, 200 and 300 foot (30, 60 and 90 m) visibilities. Associated with each visibility, a percentile speed from Study II was identified which tended to result in an "optimum" traffic flow. Although the differences between speeds were small, the following percentile speeds tended to be numerically advantageous:

100 ft. (30 m) Visibility - 15th percentile speed 5 MPH (8 km/h)
200 ft. (60 m) Visibility - 50th percentile speed 15 MPH (25 km/h)
300 ft. (90 m) Visibility - 85th percentile speed 25 MPH (40 km/h)

These speeds were posted on the variable message sign prior to the fog for each visibility condition.

The four levels of hazards consisted of: a simulated slow-moving vehicle ahead of the subject driver (Level I); a following vehicle behind the driver (Level II); both a leading and following vehicle (Level III); and none (Level IV). For the condition requiring a vehicle ahead of the subject, an illusion rather than an actual hazard was used for safety purposes.

To accomplish the illusion of a vehicle ahead, a boom with taillights was erected just prior to the fog zone such that the lights could be positioned over the road (see Figure 30). As the subject proceeded down the road, the taillights were visible and appeared as a slow-moving vehicle ahead of the subject. The taillights were located over the right-hand lane and three feet above the ground. As the subject approached the lights, they were gradually dimmed. This gave the appearance that the vehicle had gone into the fog. The boom was then moved out of the traffic lane into its resting position which was hidden from the subject's view.

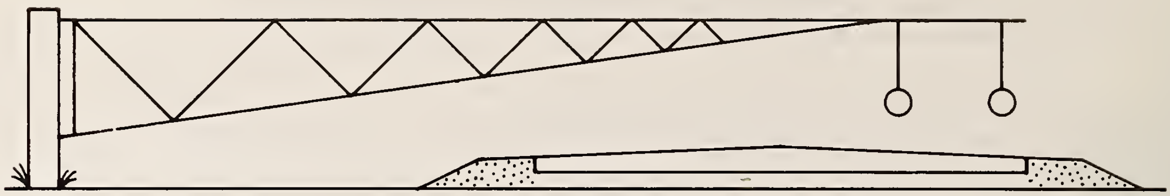


Figure 30. Boom Schematic

For the following vehicle condition, an actual vehicle was used. A State vehicle (with a State employee driving it) pulled on the road behind the subject and followed the subject down the test track until he entered the fog zone and no longer had visual contact with the following vehicle. The State vehicle would then turn off the test track and circle back over another road for the next run.

To provide the two information levels, a variable message sign was contructed and installed 500 feet (150 m) prior to the fog. This sign consisted of an internally illuminated sign with three removable panels (see Figure 31). These panels were changed based on test condition and fog density.

Figure 31. Variable Message Speed Sign

The sign was manually operated in either the on, off, or flashing mode of operation. For the familiarity run, the sign was on continuously with 55 MPH (90 km/h) posted. For the fog runs, the sign was turned off while the visibilities were being obtained and the numerical speed value inserted. The sign was turned on in the flashing mode when the subject's vehicle reached Radar 1 (1000 feet (300 m) before the sign).

On the runs in which the following vehicle was used, the vehicle and driver were located on a side road which intersected the test road at a point approximately 300 feet (90 m) from where the subject started. The State vehicle was not visible to subjects prior to the start of the runs.

When the subject started down the test road, the state vehicle started down the side road. Its headlights would be visible to the subject. The movements of the two vehicles were sequenced such that the state vehicle turned on the test track approximately 500 feet (150 m) behind the subject's vehicle. This distance was maintained until the vehicles entered radar coverage at which time it was necessary for the following vehicle to remain one radar's length behind the subject to avoid radar interference.

On the runs during which the boom was used, an experimenter positioned the boom over the road with the lights on prior to the start of the run. The boom was located approximately 300 feet (90 m) before the fog and was only visible to the subject for a distance of approximately 1000 feet (300 m) due to a slight vertical curve in the road. As the subject passed Radar 1 (as indicated by the Test Coordinator), the boom operator activated the timing circuit which gradually dimmed the taillights. The time required was approximately six seconds. This value was determined during pilot studies to give the most realistic effect of a vehicle disappearing into fog. When the lights were completely extinguished, the boom operator moved the boom out of the traffic lane and into its resting position out of the subject's view.

All subjects were given one familiarity run followed by one fog run. During the familiarity runs, the speed sign was illuminated in its continuous mode of operation with 55 MPH (90 km/h) posted. A blank panel was inserted in place of the "Fog" panel during these runs. For the fog runs, the sign was operated in the flashing mode (50-60 per min.) with the word "SPEED" and the appropriate numerical value for Level I, or "FOG," "SPEED" and the appropriate value for Level II.

Results

The results of this study consisted of the driver's speed records for the fog runs for Information Levels I and II. A total of 123 subjects were tested; 70 under Information Level I and 50 under Information Level II. For various reasons 65 runs were eliminated resulting in 58 usable runs. The distribution of runs by conditions is contained in Table 6.

Table 6. Distribution of Runs by Conditions

	Information Level I			Information Level II		
Visibility 1 foot = .305 m	100'	200'	300'	100'	200'	300'
Follow	2	3	1	5	4	-
Lead	3	3	2	3	5	-
Both	3	3	1	5	2	1
None	2	4	1	3	2	-

The results of the analysis for subjects speed in the Fog Zone are contained in Table 7. Insufficient data was obtained for the 300 foot (90 m) condition to include it in the analysis. The Analysis of Variance Summary conducted on the cell means is contained in Table 8.

Table 7. Mean Speeds in Fog Zone - MPH

VISIBILITIES								
	Information Level I (Mean Speeds)				Information Level II (Mean Speeds)			
	100	200	$\overline{X}$	σ	100	200	$\overline{X}$	σ
Follow	4.96	11.45	10.43	4.16	9.57	7.59	8.05	3.26
	6.21	15.06			7.11	13.9		
		14.45			5.79	12.83		
					3.19	6.07		
					6.43			
Lead	4.93	15.29			7.63	7.29		
	5.00	18.06	10.07	5.67	12.32	10.67	8.68	2.08
	3.81	13.31			5.75	7.67		
						9.43		
Both	4.75	15.19	9.83	5.34	5.71	8.63		
	7.08	18.84			7.93	5.43	6.79	1.50
	4.72	8.39			7.44			
					8.06			
					4.33			
None	6.79	10.29	12.75	7.60	10.0	7.88		
	7.19	29.14			5.5	5.92	6.60	2.60
		10.31			9.33	8.60		
		12.79			7.25	2.67		
					3.20			
$\overline{X}$	5.54	14.81			6.98	8.18		
σ	1.11	5.06			2.39	2.82		

Table 8. Analysis of Variance Summary

Source	DF	MS	F	P
Information	1	27.35	2.14	.25
Hazards	3	.71		
Visibilities	1	99.5	7.77	.07
Info. X Hazards	3	2.56		
Info. X Visibilities	1	66.75	5.21	.10
Hazards X Visibilities	3	.78		
Info. X Hazards X Visibilities	3	1.85		
Within Cell	3	12.81		

An inspection of the data in Table 8 indicates that the hazards had little or no effect upon driver performance but that there was an effect due to information levels and visibilities. Although not significant at the .05 level, the data did indicate a trend. In addition, an interaction existed between information and visibilities. The speeds for the 100 foot (30 m) visibility condition are lower than the speeds for the 200 foot (60 m) condition and the overall speeds for Information Level II are lower than for Information Level I. However, the increase in speeds for Information Level I between 100 and 200 foot (30-60 m) visibility are substantially higher than the increase for Information Level II. A reversal also appears in the 100 foot (30 m) condition with Information Level II showing a higher speed than in Information Level I. It should be noted, however, that for the 200 foot (60 m) visibility, Information Level I resulted in the speeds being closer to the posted speed (15 MPH) (25 km/h). These results indicated that the addition of the hazard type tended to reduce speeds but did not improve adherence to the posted speeds.

In terms of the speeds profiles, Figures 32 and 33 contain the curves for Information Levels I and II at the 100 foot and 200 foot (300 and 60 m) visibilities. Since hazards had little effect upon driver performance, these curves were obtained by summary over the remaining conditions. For the 100 foot (30 m) visibility, Information Level I tended to have a higher mean speed at the beginning of the speed monitoring area but a lower speed as they approached the sign and passed through the fog. Level I also had lower standard deviations both prior to and in the fog zone. Both curves tend to be similar both in shape and where the peak occurs just prior to the fog. For the 200 foot (60 m) visibility, Information Level I resulted in higher speeds both prior to and in the fog. This condition also had substantially higher standard deviations prior to the fog and slightly higher in the fog. The shape of the curves are more different than in the case of the 100 foot (30 m) visibility with the peak for Level II occurring further into the fog bank.

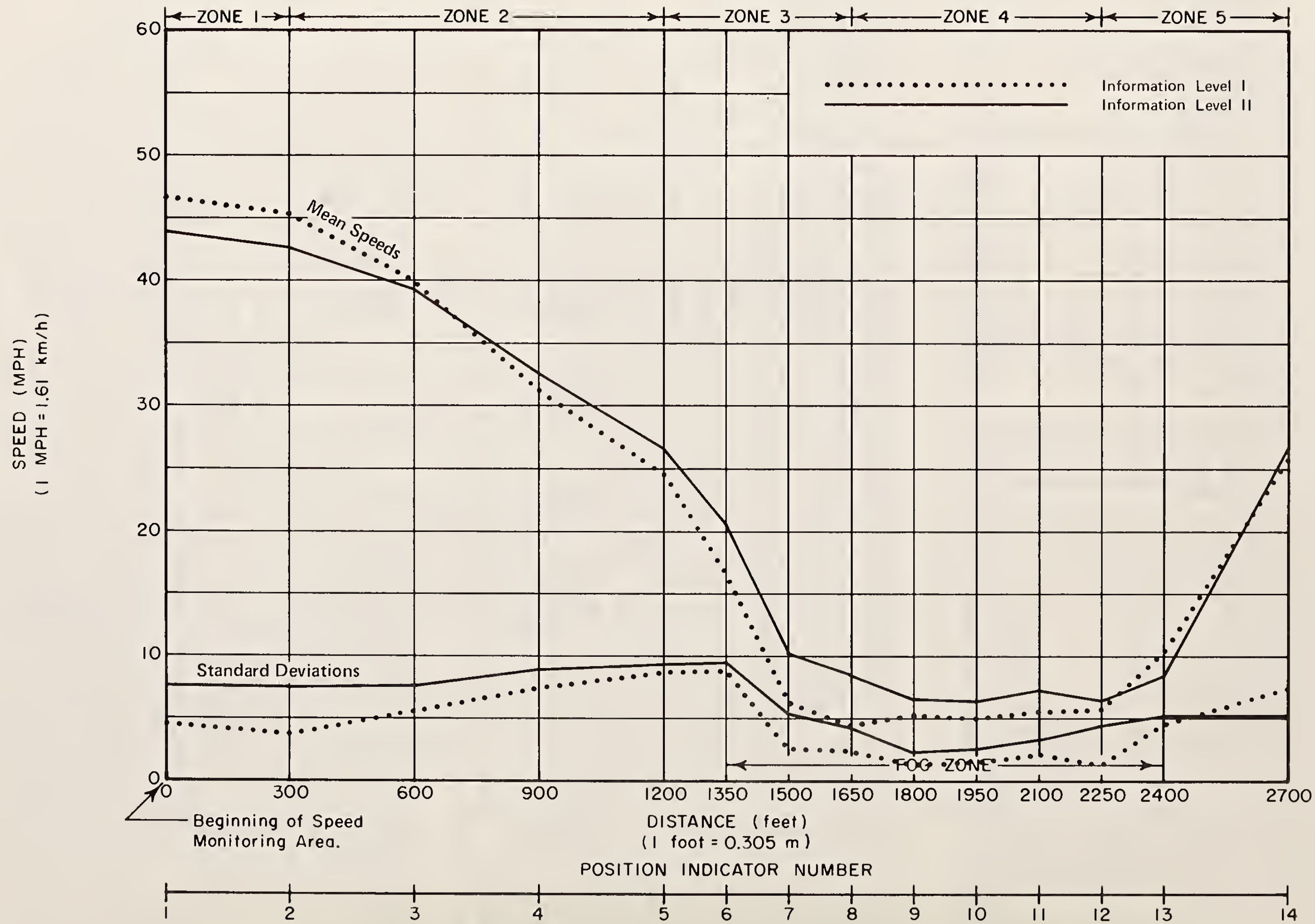


Figure 32. Study III, Condition I, 100-Feet Visibility Information Level I vs. Level II

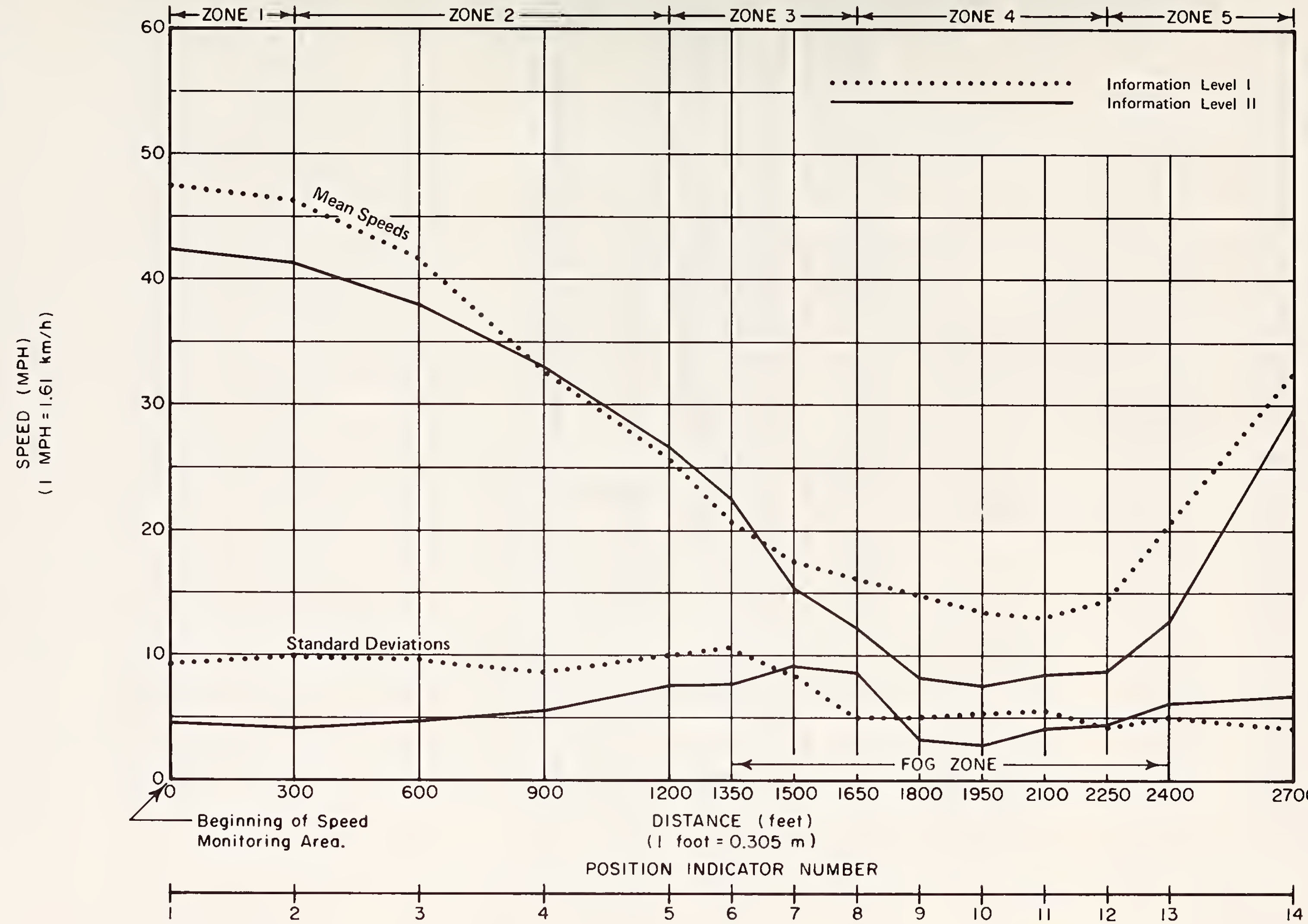


Figure 33. Study III, Condition II, 200-Feet Visibility
Information Level I vs. Level II

The analysis of the Subject Data Form yielded results similar to the previous studies. One question which deserves consideration concerns the number of drivers who were aware of other traffic (hazards) on the road given that the hazard was present. Table 9 contains the frequencies for Information Levels I and II of the drivers who were or were not aware of other traffic.

Table 9. Frequency of Subjects Being Aware of Hazards

	Aware	Not Aware
Information Level I	19	2
Information Level II	16	9

Chi Square test of significance for Table 9 was significant beyond the .01 level of confidence. This suggests that Information Level II may have been drawing the subjects attention to the sign more than Information Level I. This hypothesis is supported by a further analysis of the data. Both drivers for Information Level I and five of the nine from Level II who were not aware of other traffic missed the Leading Hazard. It would appear that in these cases, the driver's attention was drawn to the sign, but more so for Level II than Level I. An analysis of the subject speed data for those who were or were not aware of the hazards could not be completed due to the small sample sizes.

Comparisons with the data from previous studies were conducted; however, some of the data was inappropriate and the results non-conclusive. Consequently, they are not presented here.

STUDY IV - SIGNING

The major objective of this study was to investigate the effects of different types, amounts and display characteristics of advisory signing. The utility of advisory sign interconnection and the posting of differential speeds on successive signs was also studied.

Procedures

For this study, six different signing schemes were created. These signing schemes ranged from a simple one-sign system to a complex nine-sign system with flashing lights (see Figure 34). All signs had a standard black on white sign facing with 3/4 inch (2 cm) plywood backing. Also, two test sessions were conducted using two-way radio to broadcast messages to the subjects. This auditory signing was also included in this study.

Prior to each test session, a particular sign scheme was erected on the test site. All subjects were given two familiarity runs prior to activating the fog system. During these familiarity runs, all signs were visible but the flashing lights were off.

After the second familiarity run was completed, the flashing lights were activated and the fog bank was generated. Each subject was given only one fog run in this study. After the fog run, the subjects were debriefed as in previous studies (see Appendixes H and I).

Results

The basic data from this study consisted of the subjects speed records for the fog run and their comments in the subject data forms.

This study was conducted in 13 test sessions from July 28 to November 18, 1976. A total of 93 subjects completed 186 clear runs (familiarity runs) and 93 fog runs. Fourteen runs were eliminated due to a visibility differential greater than 100 feet (30 m) between the north and south sections of the fog zone. The remaining 79 runs were divided into two visibility groups, the high visibility range for visibilities from 250 feet to 500 feet (75 m to 150 m) and the low visibility range from 0 feet to 249 feet (0 m to 75 m). The frequency distribution of runs by visibility range is contained in Table 10, and the frequency distribution of runs by visual condition and sign scheme is contained in Table 11.

Table 10. Frequency Distribution of Runs by Visibility Range

Visibility Range (feet)	50	100	150	200	250-	250+	300	350	400	450	500-
Number of Runs	1	18	12	4	5	6	16	6	9	1	1

Distance from Beginning of Fog Zone (Feet) (1 foot = 0.305 m)	SIGNING SCHEME NUMBERS					
	1	2	3	4	5	6
2500		FOG ZONE AHEAO	FOG ZONE AHEAO	FOG ZONE AHEAO	FOG ZONE AHEAO	FOG ZONE AHEAO
2000					FOG ZONE NEXT 1 MILE	HAZAROOUS FOG ZONE NEXT 1 MILE
1500			* FOG * AHEAO WHEN FLASHING	* FOG * AHEAD WHEN FLASHING	* FOG * AHEAD WHEN FLASHING	* FOG * AHEAO WHEN FLASHING
1000				* SLOW TO * 35 WHEN FLASHING	* SLOW TO * 35 WHEN FLASHING	* CAUTION * SLOW TO 35 WHEN FLASHING
500	* FOG * SPEEO 15 WHEN FLASHING	* FOG * SPEEO 15 WHEN FLASHING	* FOG * SPEED 15 WHEN FLASHING	* FOG * SPEEO 15 WHEN FLASHING	* FOG * SPEEO 15 WHEN FLASHING	* WARNING * SAFE FOG SPEEO 15 WHEN FLASHING
0		MAINTAIN 15 IN FOG	* MAINTAIN * 15 WHEN FLASHING	* MAINTAIN * 15 WHEN FLASHING	* MAINTAIN * 15 WHEN FLASHING	* MAINTAIN * 15 WHEN FLASHING NO STOPPING
-400				* MAINTAIN * 15 WHEN FLASHING	* MAINTAIN * 15 WHEN FLASHING	* MAINTAIN * 15 WHEN FLASHING NO STOPPING
-725					* MAINTAIN * 15 WHEN FLASHING	* MAINTAIN * 15 WHEN FLASHING NO STOPPING
-1100					END FOG ZONE	* ENO * FOG ZONE

Figure 34. Signing Schemes and the Relative Position of the Signs with Respect to the Leading Edge of the Fog

Table 11. Frequency Distribution of Runs by Visual Condition and Sign Scheme

Visibility	Signing Scheme Number						
	1	2	3	4	5	6	Radio
High	6	5	5	7	5	5	5
Low	6	5	6	5	7	5	7

The curves of the mean speed for the fog runs are contained in Figures 35 and 37. Figures 36 and 38 are curves of the standard deviation of the mean speeds for the fog runs.

An inspection of Figures 35 and 36 shows that some trends did exist for the high visibility condition. As the quantity of information (i.e. number of signs) increased, the speed prior to entering the fog bank decreased. Sign schemes 4, 5 and 6 showed relatively smooth decelerations prior to the beginning of the fog zone while schemes 1, 2 and 3 showed rather sudden deceleration starting near the leading edge of the fog bank. Once into the fog bank, the effects of the different signing levels were negligible. The standard deviation of the mean speeds ranged from 0 MPH (0 km/h) to 12 MPH (19 km/h). The maximum standard deviation occurred with sign scheme 1 near the leading edge of the fog bank. The consistently lowest standard deviation occurred with sign scheme 5 averaging approximately 5 MPH (8 km/h) through the entire data acquisition section (see Figure 36).

The tests with the radio broadcast messages showed promising results in the high visibility case. In this test, all signing was removed from the test track and the messages of sign scheme 6 were broadcast to the drivers. The broadcast was timed so that the drivers received the broadcast message at the same point they would have read the same message in sign scheme 6. In comparing the mean speed graphs of sign scheme 6 and the radio, it is obvious that the initial speeds were significantly higher (15 MPH (25 km/h)) in the radio case. Deceleration rates through zone 2 were about the same for both cases; however, in the radio case the deceleration rate increased slightly in zones 3 and 4 while it tended to flatten through those zones in sign scheme 6. A comparison of the standard deviation of the mean speeds for the two cases indicated that the standard deviations were consistently lower by 1 to 4 MPH (1 to 6 km/h) in the radio case (see Figure 36).

The same basic comparisons were made in the low visibility case. The findings were quite similar in that, with the exception of sign scheme 1, as the number of signs increased, the initial speeds decreased.

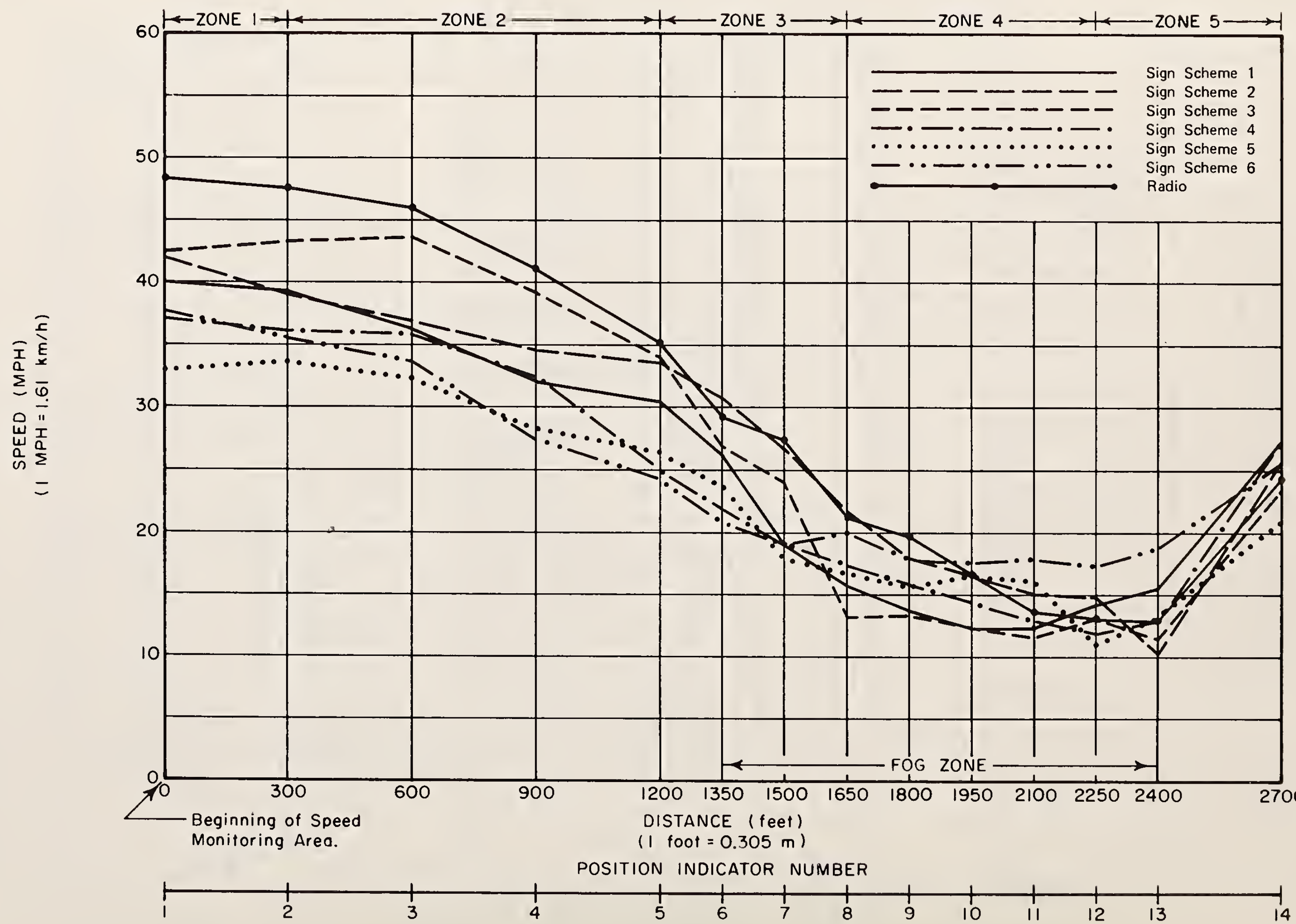


Figure 35. Mean Speeds of Fog Runs - High Visibility

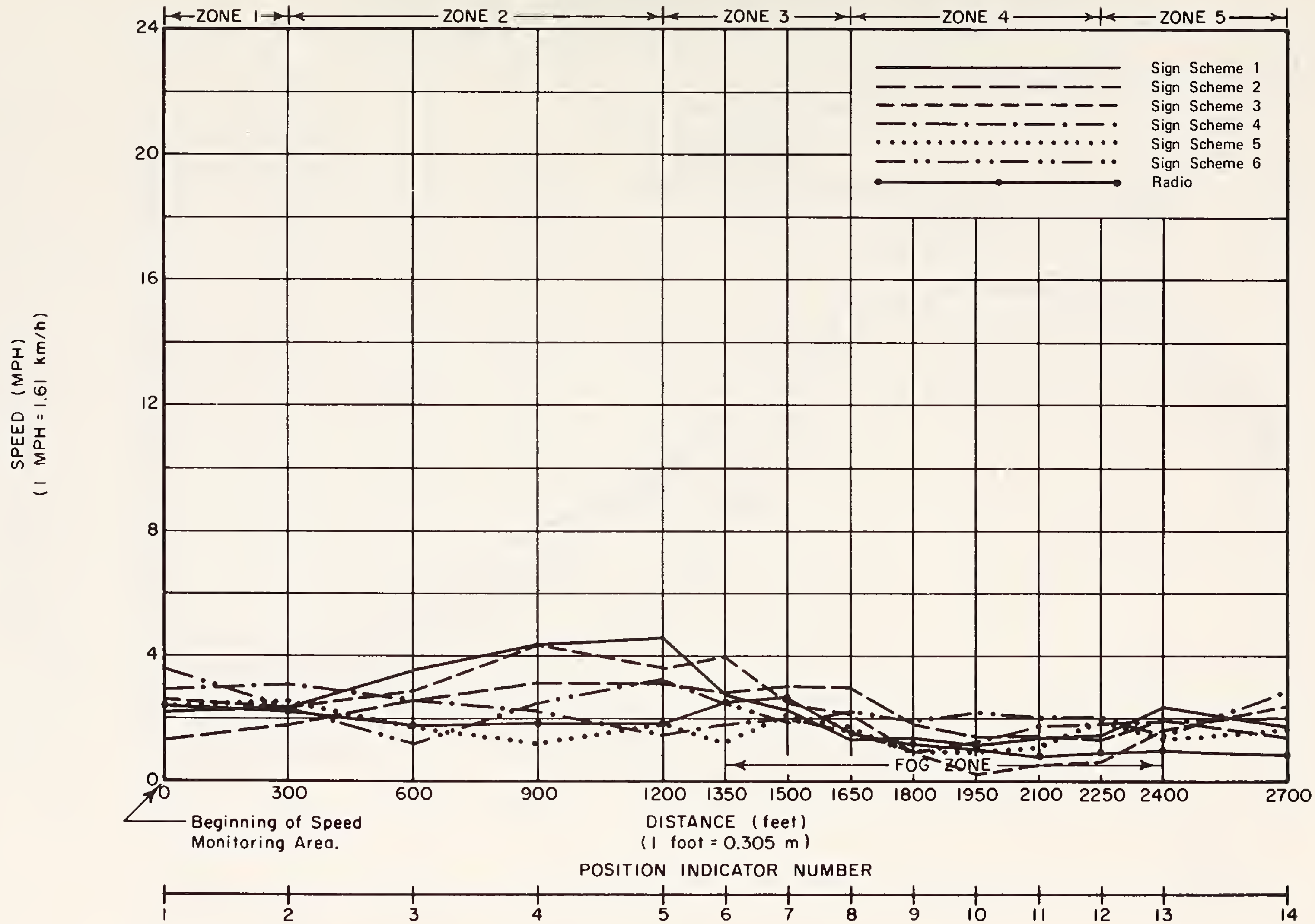


Figure 36. Standard Deviations of Mean Speeds of Fog Runs-
High Visibility

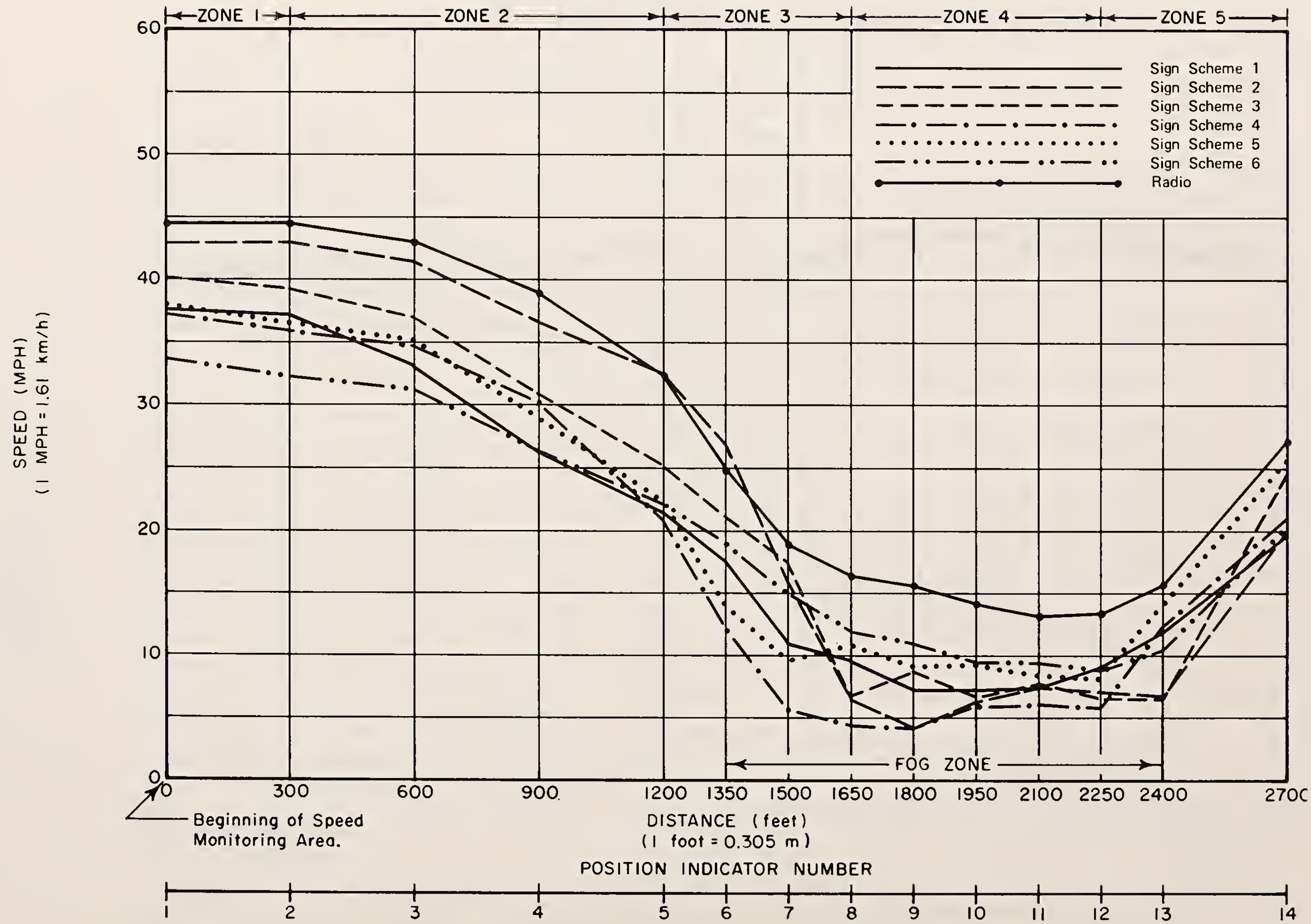


Figure 37. Mean Speeds of Fog Runs - Low Visibility

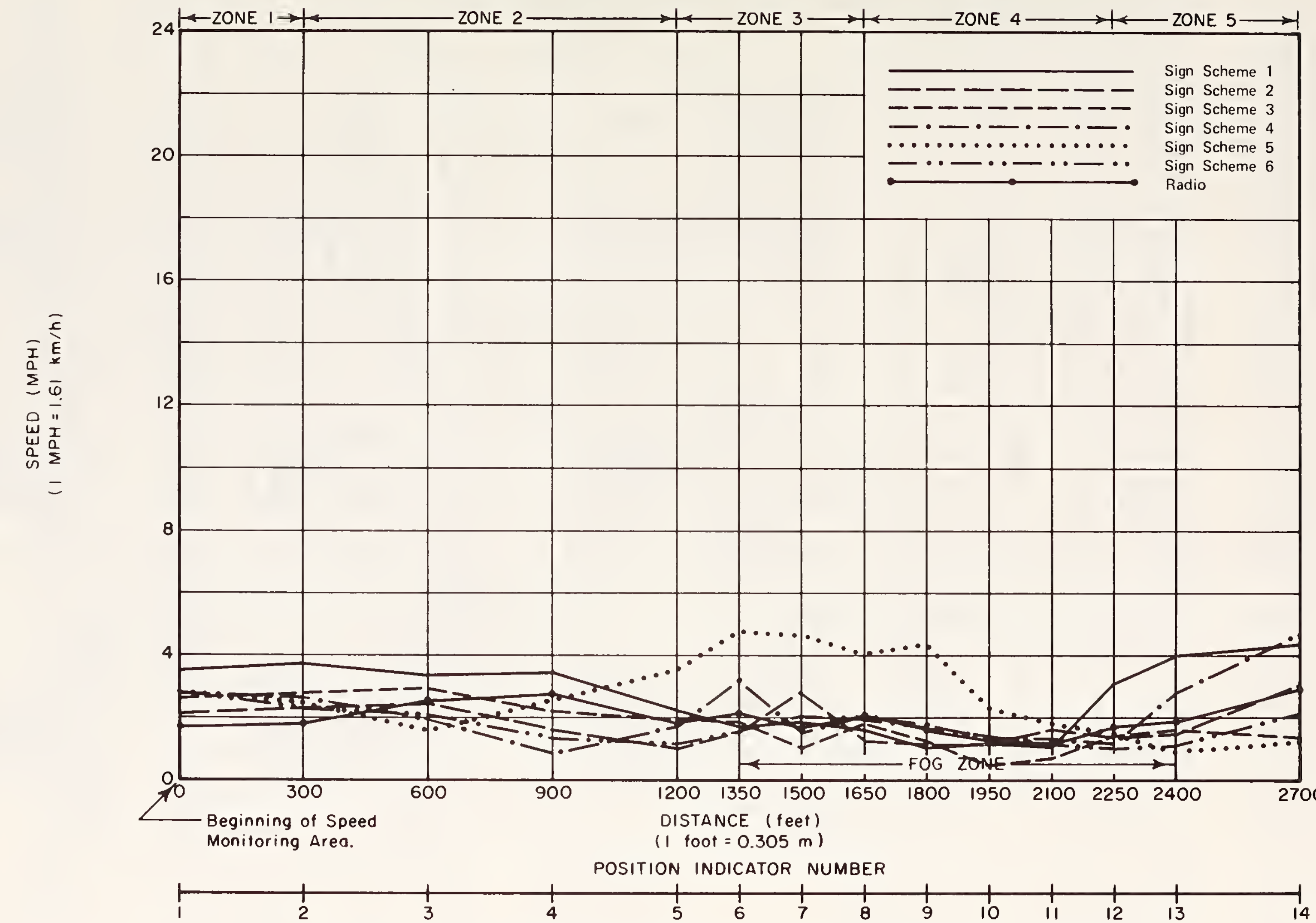


Figure 38. Standard Deviations of Mean Speeds of Fog Runs-
Low Visibility

The deceleration curves were fairly uniform in zone 2 while deceleration rates increased rapidly and apparently randomly with respect to sign schemes in zone 3. Once in the fog bank, vehicle speeds slowed to an average speed of 8 MPH (13 km/h).

When comparing sign scheme 6 with the radio in the low visibility case, it is obvious that the mean speeds for the radio case through the fog were continuously higher by 4 MPH (6 km/h) than sign scheme 6 case. The minimum point on the mean speed curve for the radio was 13 MPH (21 km/h) while the minimum point for sign scheme 6 was 9 MPH (14 km/h).

An analysis of variance was conducted on the mean speed data by zone for zones 2, 3 and 4. The values in Table 12 represent the analysis of variance summary of mean speeds through zone 2. Tables 13 and 14 represent the variance summary for zones 3 and 4 respectively. In these tables, the following abbreviations are used: Sum of the squares (SS), Degree of freedom (df), Mean squares (ms), and the F value for test of significance (F).

Table 12. Analysis of Variance Summary of Mean Speeds Through Zone 2

Source of Variation	SS	df	ms	F
Visibility	96.17	1	96.17	
Signing	1253.54	6	208.92	6.00*
Interaction	186.64	6	31.11	
Within Cell	2262.26	65	34.80	

Table 13. Analysis of Variance Summary of Mean Speeds Through Zone 3

Source of Variation	SS	df	ms	F
Visibility	1003.36	1	1003.36	32.62*
Signing	932.14	6	155.36	5.05*
Interaction	73.38	6	12.23	
Within Cell	1999.40	65	30.76	

Table 14. Analysis of Variance Summary of Mean Speeds Through Zone 4

Source of Variation	SS	df	ms	F
Visibility	857.76	1	857.76	66.65*
Signing	299.67	6	49.95	3.88*
Interaction	129.57	6	21.60	
Within Cell	836.68	65	12.87	

An inspection of Table 12 indicates that the amount and/or method of information presentation was significant beyond the 0.05 level of confidence in zone 2. However, as expected, the visibility had little or no effect in zone 2.

In zone 3 where drivers were well aware of the actual fog bank, both the visibility conditions and the signing conditions were significant beyond the 0.05 level of confidence. Also in zone 4, which was completely within the fog bank, both the visibility conditions and the signing conditions were significant at the 0.05 level. Further analysis showed that there was very little difference between signing systems; the primary difference was between the radio system and the signs. Table 15 shows the significantly different signing schemes by zone.

Table 15. Summary of Significantly Different Information System by Zone

Zone 2	Zone 3	Zone 4
Radio Vs. Sign 6 Radio Vs. Sign 5 Radio Vs. Sign 4 Radio Vs. Sign 1	Radio Vs. Sign 5 Radio Vs. Sign 4 Sign 5 Vs. Sign 2 Sign 4 Vs. Sign 2	Radio Vs. Sign 4 Radio Vs. Sign 3 Radio Vs. Sign 1

The utility of using speed differentials on successive signs was also investigated in this study. In sign schemes 4 through 6, a sign with a speed of 35 MPH (55 km/h) was posted 1000 feet (300 m) in advance of the fog bank. Then at 500 feet (150 m) before the fog, a sign with a speed of 15 MPH (25 km/h) was posted.

As previously mentioned, Figure 35 shows that for the high visibility case, there was a difference between sign schemes 1, 2 and 3 and schemes 4, 5 and 6. With sign schemes 4, 5 and 6, the vehicles had started decelerating and were at an average mean speed of 36 MPH (58 km/h) at the point of the 35 MPH (55 km/h) sign. At the first 15 MPH (25 km/h) sign 500 feet (150 m) before the fog, the average mean speed was 29 MPH (47 km/h). The vehicles continued decelerating at a fairly constant rate into and through the fog zone. For sign schemes 1, 2 and 3, the vehicles were at an average mean speed of 41 MPH (66 km/h) 1000 feet (300 m) before the fog. These vehicles decelerated to an average mean speed of 35 MPH (55 km/h) at the point of the first 15 MPH (25 km/h) sign 500 feet (150 m) before the fog. Approximately 150 feet (45 m) before the fog, the vehicles started a rapid deceleration.

For the low visibility case, similar differences could be detected bewteen those schemes with speed differentials and those shemes without speed differentials.

The speed curves for both high and low visibility were also analyzed on a sign by sign basis within the data collection area to determine which, if any, of the signs produced obvious benefits.

The first sign which we could accurately analyze was the "SLOW TO 35 WHEN FLASHING" sign which was 1000 feet (300 m) in advance of the fog zone. The addition of this sign produced a 5.7 MPH (9.2 km/h) reduction in speed under the high visibility condition and a 4.3 MPH (6.9 km/h) reduction in the low visibility case. The speed reduction in both cases produced a mean speed of 35 MPH (56 km/h) at the sign location. Adding the word "CAUTION" to this sign had no effect on the results.

The next sign, located 500 feet (150 m) prior to the fog, was used in all tests; therefore, its effect could not be analyzed.

At the leading edge of the fog bank a "MAINTAIN 15 IN FOG" sign was posted for sign scheme 2 and was changed to "MAINTAIN 15 WHEN FLASHING" for schemes 3 through 6. When the "MAINTAIN 15 IN FOG" sign was posted, a 5 MPH (8 km/h) increase in speed was noted. When the "MAINTAIN 15 WHEN FLASHING" was posted, a 9.25 MPH (14.9 km/h) speed reduction was registered in the low visibility case and a 4.5 MPH (7.2 km/h) reduction in the high visibility case. This resulted in an overall reduction to a mean speed of approximately 20 MPH (32 km/h).

The second and third "MAINTAIN 15 WHEN FLASHING" signs, 400 feet and 725 feet (120 m and 220 m) into the fog bank, produced an increase in speed in the area over the cases where no signs were in this area. These signs produced an increase of approximately 2 mph (3 km/h) to a mean speed of 9 mph (14 km/h). The addition of a "NO STOPPING" rider to the bottom of these signs resulted in an additional increase of 1 to 2 mph (1 to 3 km/h). These increases in speed are deemed favorable for two reasons; 1) it shows the type of message which drivers respond to, and 2) it shows that signing within the fog zone does influence drivers.

The last sign "END FOG ZONE" did not appear to have an effect on the subject's driving behavior.

STUDY V - DELINEATION

The objective of this study was the investigation of the utility of augmenting the advisory signing with centerline and edgeline delineation consisting of raised reflective pavement markers.

Procedures

For this study three levels of delineation were investigated under two different levels of signing. The two signing levels correspond to signing schemes numbers 1 and 6 from Study IV. The three levels of delineation consisted of reflective centerline and edgeline stripes with no raised reflective markers, raised reflective markers on 40-foot (12 m) centers and markers on 20-foot (6 m) centers. The markers were used only in the actual fog zone. White markers were utilized on the centerline and right edgeline while yellow markers were used on the left edgeline. The third variable, visibility, was once again divided into two groups, high visibility (visibility above 250 feet (75 m)) and low visibility (visibility below 250 feet (75 m)).

This study was conducted in seven sessions from September 10 to October 26, 1976. As in the previous study, the test subjects were given two familiarity runs prior to their fog run.

Results

Data from 70 test subjects were used in this study. A total of 48 new subjects were recruited for this study; data for the remaining 22 subjects were taken from Study IV. Table 16 shows the frequency distribution of runs for this study.

Table 16. Frequency Distribution of Runs

	No Del. Low Sign	No Del. High Sign	Low Del. Low Sign	Low Del. High Sign	High Del. Low Sign	High Del. High Sign
High Visibility	6	5	4	5	6	5
Low Visibility	6	5	6	10	6	6

A statistical analysis of the mean speed data was conducted for zones 2, 3 and 4. As expected, in zone 2, which is outside of the fog zone, the amount of delineation within the fog zone had no effect on the subjects' speeds. At the 0.05 significance level in zone 3, there was a significant difference in mean speeds between the high delineation and low delineation case with low signing and high visibility. In zone 4, at the 0.05 significance level, there was a significant difference in mean speeds

between the no delineation case and both the high and low delineation cases under the high signing level and low visibility level. Table 17 shows a summary of these statistically different cases.

Table 17. Summary of Statistically Different Combinations of Signing, Visibility, and Delineation

Conditions		Zone		
Signing	Visibility	2	3	4
Low	Low	-	-	-
Low	High	-	High Del. Vs. Low Del.	-
High	Low	-	-	No Vs. Low No Vs. High
High	High	-	-	-

Figures 39 through 42 are the curves of mean speeds and standard deviations for the fog runs.

Figures 39 and 41 show that, in the low visibility case, the addition of the reflective buttons did tend to increase the mean speeds through the fog zone by 3 to 13 MPH (5 to 21 km/h) for the high signing case and by 0 to 10 MPH (0 to 16 km/h) in the low signing case. The standard deviations were about the same for the delineation and no delineation cases with high signing but they were generally higher for the delineation cases with low signing. These two figures also show that near the end of the fog zone, acceleration rates and standard deviations were higher when the reflective buttons were utilized.

Figures 40 and 42 indicate that in the high visibility cases, no apparent trends were set with respect to the utility of using raised reflective delineators. These curves do tend to indicate that the delineation system which produced the highest mean speeds in the fog also produced the highest standard deviations. Since we are trying to maximize the traffic flow stability while maintaining a satisfactory speed, it appears that one must make a trade off with regard to delineation.

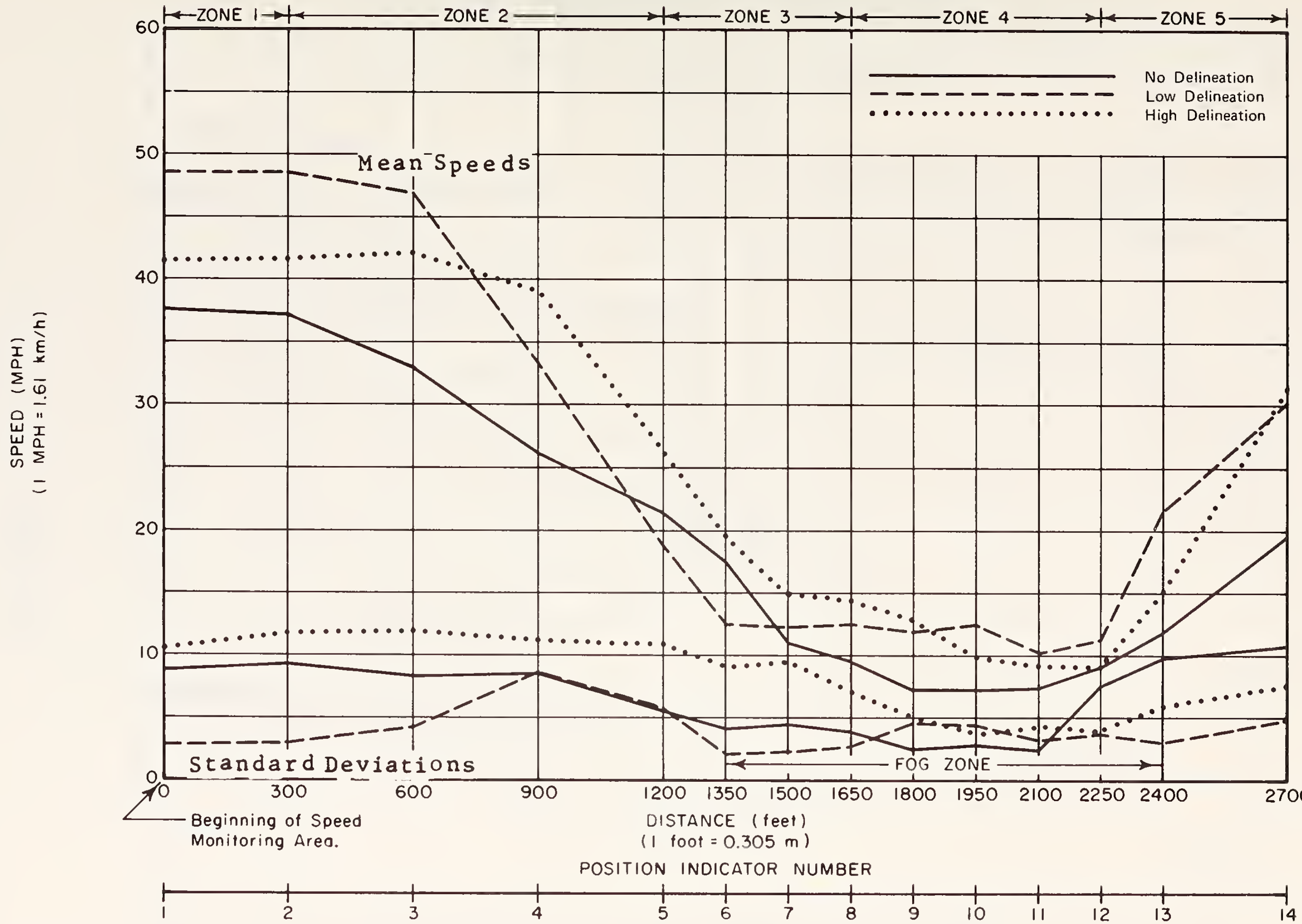


Figure 39. Mean Speeds and Standard Deviations
Low Signing - Low Visibility

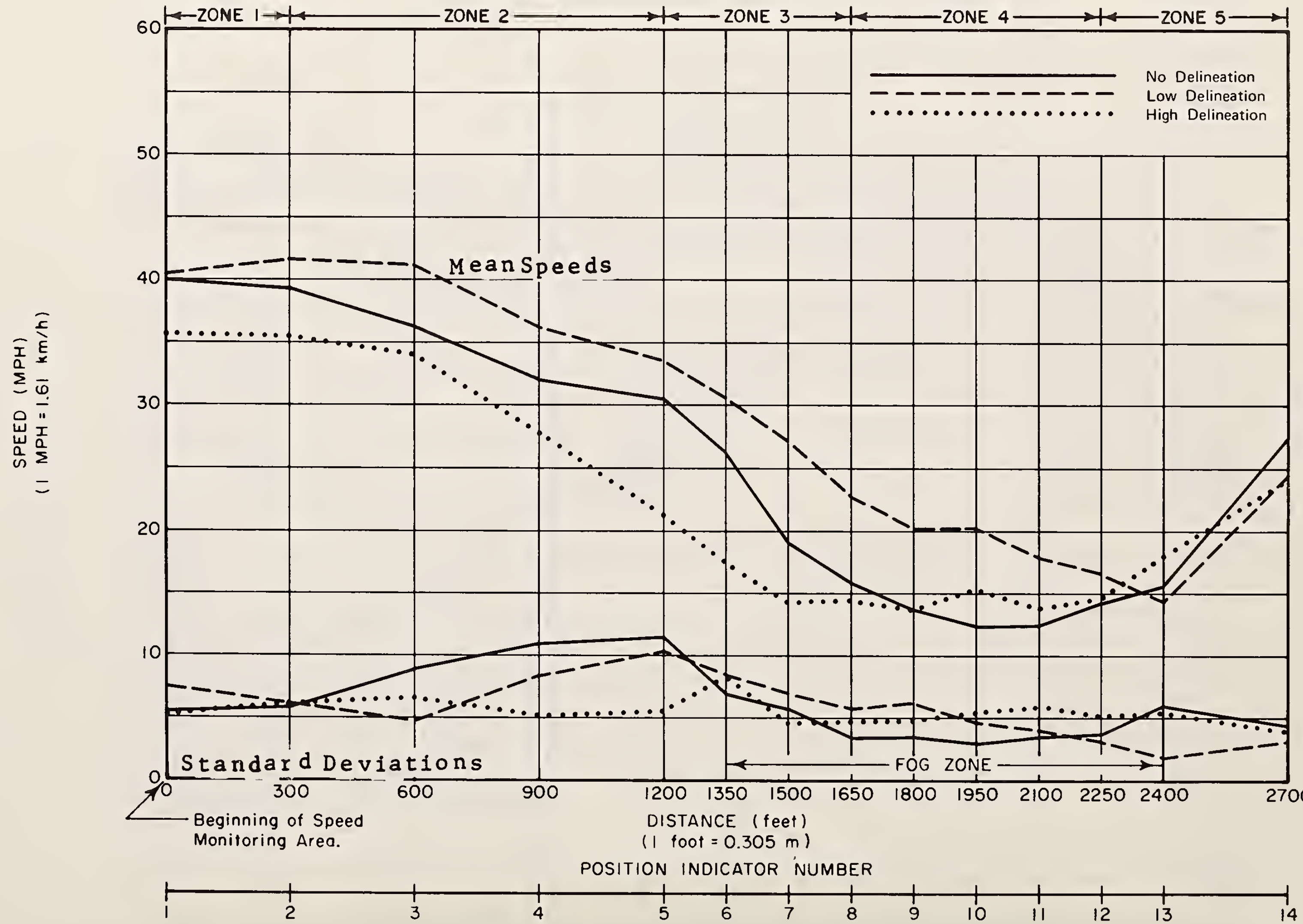


Figure 40. Mean Speeds and Standard Deviations
Low Signing - High Visibility

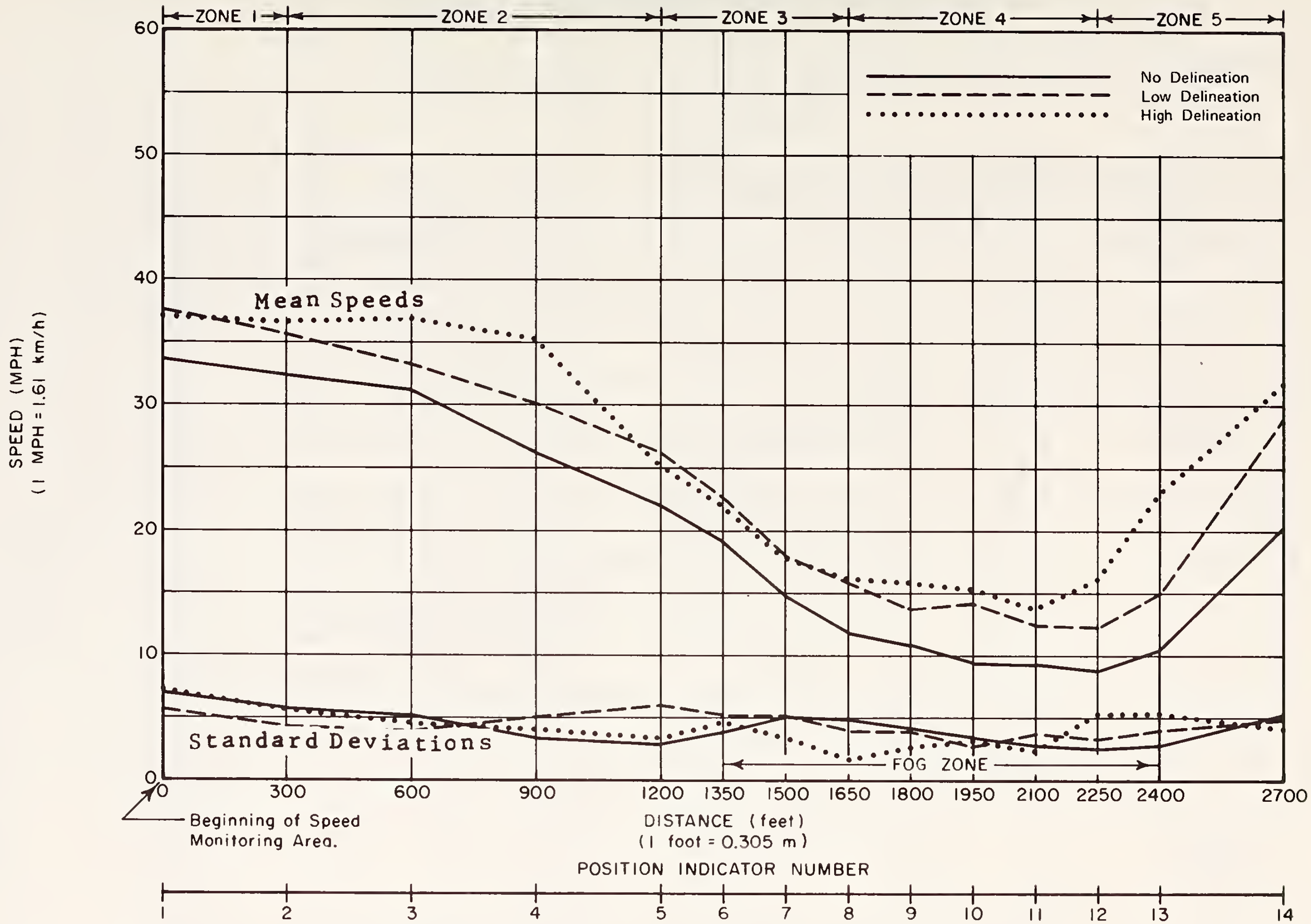


Figure 41. Mean Speeds and Standard Deviations
High Signing - Low Visibility

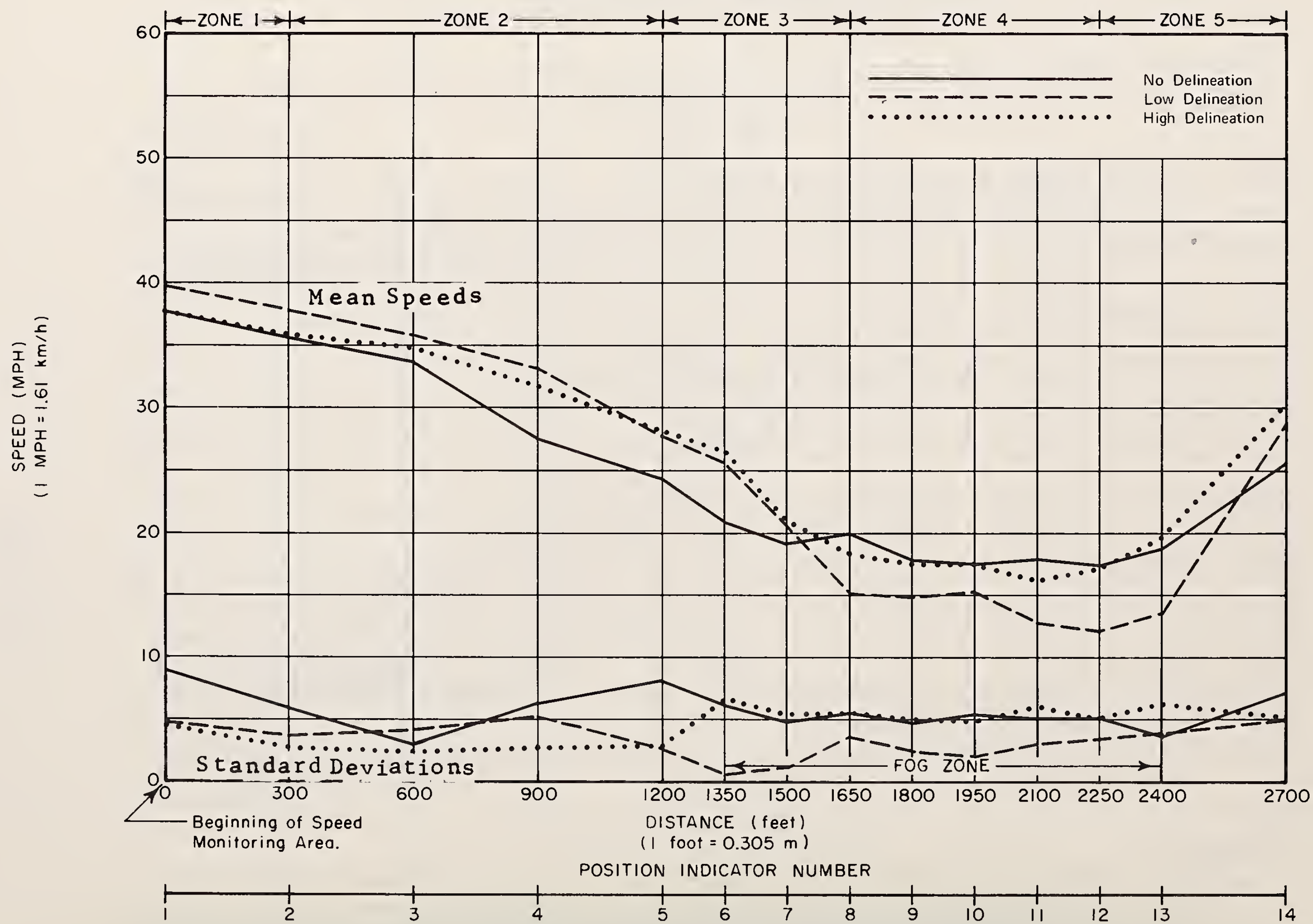


Figure 42. Mean Speeds and Standard Deviations
High Signing - High Visibility

STUDY VI - CRY WOLF

The objective of this study was to determine the consistency with which speed advisory information must reflect the driving conditions ahead, and also the relearning time required by drivers who have been exposed to unrealistic information.

Procedures

This study was conducted under two levels of signing. In the high signing case, the signs from sign scheme 6 of Study IV were used and for the low signing case, sign scheme 1 from Study IV was posted.

As in the previous study, each subject was given two familiarity runs on the test track. After completion of these two runs, the flashing lights were activated and the subjects were once again run through the facility.

The speed curve for each subject's second familiarity run was used as the base speed for that subject. Three points along this curve were selected as baseline speeds for comparison with future runs. The subjects were given as many "fog" runs (runs with fog signs activated) as necessary to regain their initial speeds as indicated by the three baseline speeds. Figure 43 is an example of a subject's speed curve for the low signing case.

Initially, we intended to produce fog after the subject's speed regained the baseline speed; however, this experimental design was abandoned after one test session due to safety considerations. Generally, the subjects entered the fog bank at relatively high speeds, above 40 MPH (65 km/h). The subjects then appeared to lose control of their vehicles momentarily and become disoriented in the fog. Fifty percent of the subjects either drove or skidded off the roadway in the first testing session. We felt to continue under these conditions would be unwise.

The subject instructions, data forms and debriefing information is contained in Appendixes G, H and I respectively.

Results

In this study, 30 subjects completed 60 clear runs and 216 "fog" runs. Twelve subjects were tested under a low signing condition and 18 subjects were tested under a high signing condition. Six of the subjects in the high signing study did encounter fog on their fifth "fog" run. Data from these six subjects was reduced and analyzed separately from the other 12 subjects in the high signing study.

Of the twelve subjects in the low signing study, only two subjects did not regain their baseline speeds in the number of runs allowed. These two subjects did show a gradual increase in speed as the number of runs increased but, due to time constraints, we could not continue running the

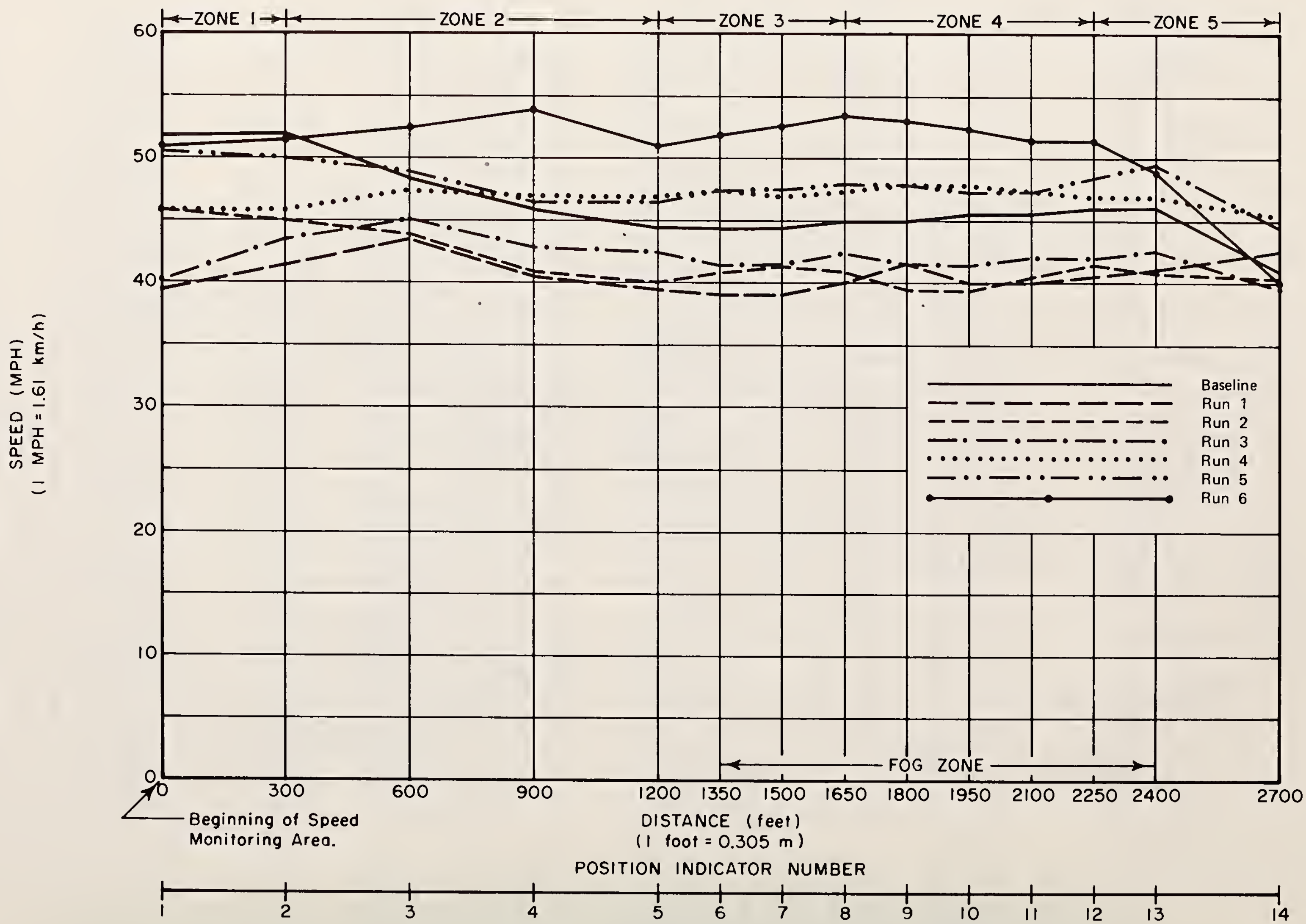


Figure 43. Example of Subject's Speed Curves for Low Signing Case

subjects until full speed was regained. The remaining 10 subjects regained their baseline speeds in an average of 3.8 runs. The minimum number of runs to regain baseline speed was two. The overall average number of runs required to either meet the baseline speed or to obtain the maximum speed below the baseline in the allotted number of runs was 4.17 runs.

In the high signing case, eight of the twelve subjects did not regain their baseline speeds in the allotted number of trials. All subjects in this part of the study were given a minimum of eight "fog" runs to regain speed. The average number of runs required to regain baseline speeds for the four subjects who did regain their speed was 5.25 runs. The average number of runs to either meet the subjects baseline speed or to obtain the maximum speed under the baseline for the allotted number of runs was 7.17 runs.

A comparison of the change in speed as a function of the number of runs indicates that the subjects had more confidence in the validity of the signing as the number of signs increased. In the low signing case, the mean change in speed was 2.55 mph/run (4.10 km/h/run) while in the high signing case this change was 1.62 mph/run (2.61 km/h/run). Statistically, this difference is not significant at the 0.05 significance level. However, the difference between the high and the low signing case in the number of runs required to regain baseline speeds is significant at the 0.05 level. In the low signing case, the mean number of runs required was 4.17 while in the high signing case the mean number of runs was 7.17. This also leads one to conclude that the more signs involved, the more faith people have in the system.

It should be noted that the subjects knew they were in a test situation and this appeared to have some effect on the test results. This is evident when reviewing data for some of the subjects in the high signing case (see Figure 44). The first "fog" run speeds dropped markedly from the baseline speeds, and then with each successive run, the speeds slowly increased to a maximum speed several runs later. After this maximum point (run 4 in Figure 44), the speeds decreased again as if the subjects were trying to second guess the results we were trying for. This phenomenom did not occur with all test subjects but it did occur often enough to warrant mentioning.

As mentioned earlier in this study, six subjects in the high signing case encountered fog on their fifth run after the baseline run. Due to time limitations, it was not practical to allow all test subjects to regain baseline speeds before generating the fog. Instead, the fog was generated after all subjects had shown a reasonable increase in speed over the first false fog run. For this test, high visibility fog (250 to 500 feet (75 to 130 m)) was used.

Table 18 shows the three baseline speeds for each run of these six subjects. An inspection of this table shows some similarities between these subjects and the other 24 subjects in this study. However, there is

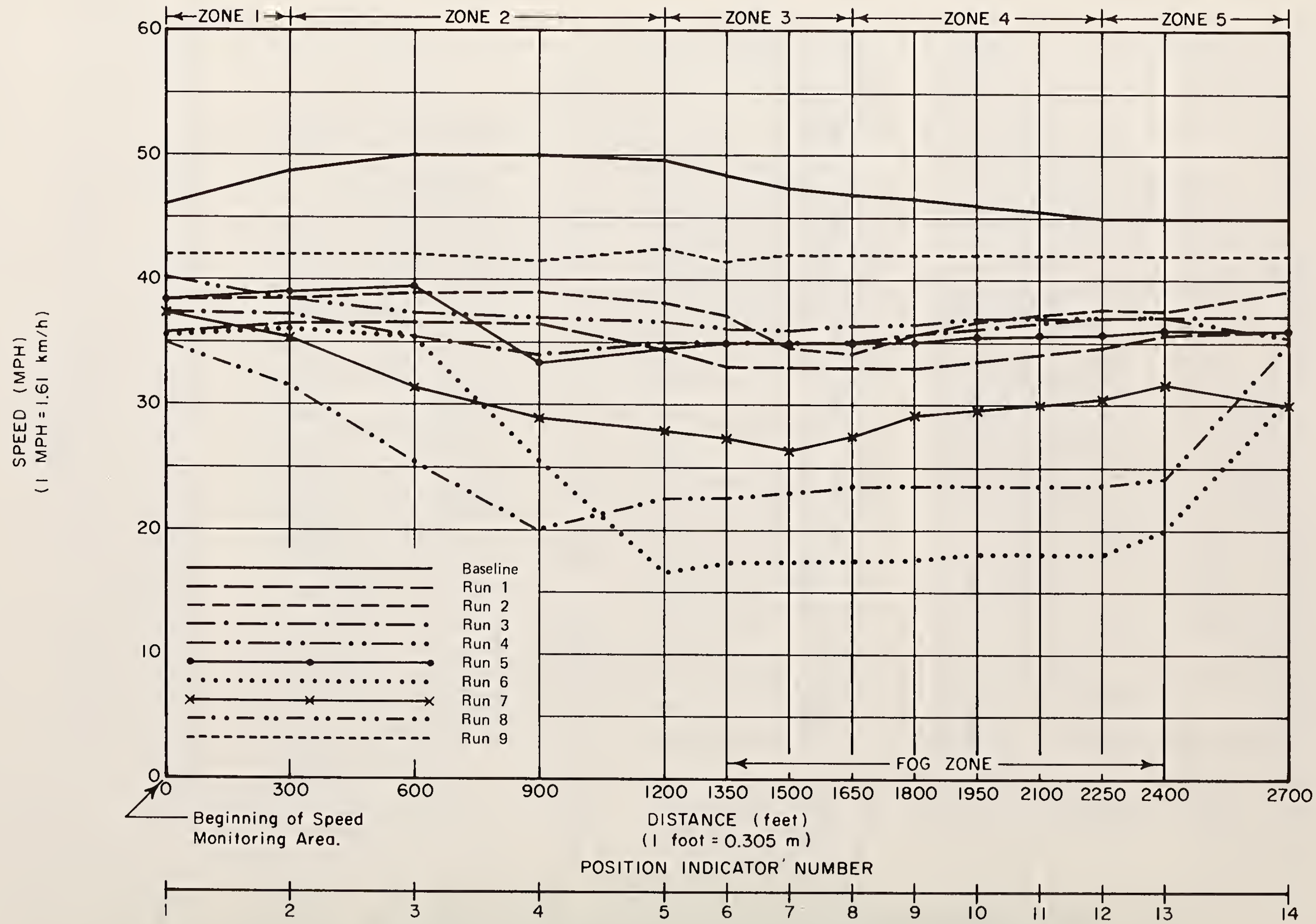


Figure 44. Example of Subject's Speed Curves for High Signing Case

Table 18. Subjects' Speeds at Reference Points

Subject	9-22-1-1			9-22-1-2			9-22-1-3		
Run \ Position	1	6	10	1	6	10	1	6	10
Baseline	52.5	54.0	54.5	59.0	62.5	62.5	50.0	49.5	48.5
1	32.5	22.0	20.0	37.5	18.5	16.5	37.5	13.0	13.0
2	38.0	33.0	31.5	36.0	17.0	18.0	39.5	12.5	13.5
3	41.5	37.0	36.5	44.0	20.0	16.0	38.5	11.5	12.0
4	-	-	-	42.0	25.5	19.0	39.5	11.0	12.5
5 (Fog)	42.0	25.0	15.5	39.5	20.5	16.0	38.5	14.0	13.0
6	49.5	50.5	49.5	58.0	60.5	57.0	43.0	44.5	51.5

Subject	9-22-1-4			9-22-1-5			9-22-1-6		
Run \ Position	1	6	10	1	6	10	1	6	10
Baseline	55.0	56.0	56.5	50.5	53.5	53.0	47.5	53.0	52.0
1	47.5	19.5	21.5	42.5	42.0	42.5	44.0	25.0	25.0
2	46.5	18.0	16.5	42.5	43.5	45.0	43.5	27.5	28.5
3	43.5	16.5	14.5	42.5	43.0	42.5	42.5	27.0	28.0
4	41.5	15.0	15.0	44.0	46.0	44.5	42.5	29.0	30.0
5 (Fog)	42.5	17.0	11.5	42.5	34.0	12.0	40.5	24.5	13.0
6	49.0	51.5	52.0	44.0	46.0	45.0	45.5	51.5	48.0

also one similarity between these six subjects which was not common to the other subjects. As with the other 24 subjects, the first false fog run for these subjects showed a substantial drop in speeds when compared to the baseline speeds. The speeds then began to slowly increase with each false fog run. After a reasonable number of false fog runs (4) a fog bank was produced without the subjects' knowledge. As expected on the following run, the actual fog run, there was a substantial decrease in speed, particularly in the fog zone. The final run, with no fog but the fog signs still activated, produced the most interesting results. The speeds on this run were all back up to the baseline speeds; in three cases this was an increase in excess of 35 MPH (56 km/h) above the previous false fog run speed. Information obtained from the subjects indicated that after the actual fog run, they completely ignored the signs because of the sign system's unreliability.

SUMMARY OF FINDINGS IN PHASE II

Initial studies indicated that, for the fog conditions as produced at the test facility, the maximum traffic flow instability occurred between 150 feet (45 m) and 500 feet (150 m) into the fog zone. The first signs of an increase in flow instability occurred approximately 750 feet (230 m) before the fog in the form of an increase in the coefficients of variation. The standard deviations first showed an increase approximately 450 feet (135 m) before the fog. The standard deviations of the mean speeds continued climbing until reaching a maximum value 150 feet (45 m) into the fog. Early studies also showed that repeated exposures to any given density of fog did not produce a significant change in driver behavior.

The method used to obtain fog density values at our test facility may yield significantly different density values than those obtained by law enforcement officers or other accident investigation agencies. Our method utilized a lighted target while other methods employ such tactics as counting the number of delineator posts or center line markers visible. What we called 200-feet (60 m) visibility in our study could very easily be called 50-feet (15 m) or less visibility when using one of the other methods.

When a single advisory sign was posted well in advance of the fog zone, a noticeable change in flow stability and vehicle speeds was recorded. In general, the speed sign appears to smooth out the mean speed curves by making the deceleration start earlier and become more gradual. Also, the posting of different percentile speeds had some effect on the drivers' behavior in terms of their mean speed and traffic flow stability. The visibility also had an effect with the lower visibility conditions resulting in lower speeds.

To determine which posted speed resulted in the smoothest traffic flow within the fog zone and to provide a direct comparison between Study I and Study II, the mean coefficients of variation for the various conditions were plotted. The presence of the fog (Study I, no speed signs) resulted in a sharp increase in the coefficient of variation. The addition of a posted speed sign generally resulted in higher coefficients of variation.

An analysis of the standard deviations of the mean speeds was also conducted. This analysis indicated that there is an optimum posted speed for each visibility condition which will produce the smoothest traffic flow. This optimum posted speed varies with visibility. At very low visibility levels, 150 feet (45 m) and below, posting the 15th percentile speed resulted in the smoothest traffic flow. When the visibility ranged from 150 to 250 feet (45 m to 75 m), posting the 50th percentile speed yielded the smoothest flow and at visibility levels greater than 250 feet (75 m), posting the 85th percentile speed provided the greatest stability.

In Study III, the Information-Hazard Study, the data implied that the addition of traffic hazards to the test track had little or no effect upon driver performance but there was an effect due to the levels of information used and visibilities. The addition of hazard type to the advance signing tended to reduce speeds but did not improve adherence to the posted speeds.

The results of the Signing Study indicated that signing is important both in advance of the fog and in the fog zone. The analysis of variance of the data collected indicated that prior to the fog, the effects of the signing were significant. Then, as the subjects entered the fog, the importance of the signing began to diminish and the effects of visibility became significant. Well into the fog, the effects of the signing were still significant, although they were becoming less significant, and the effects of the visibility were becoming more significant. A sign by sign analysis indicated that the use of speed differentials on signing prior to the fog and the use of active signing (signs with flashing lights) were beneficial. The addition of words such as "HAZARDOUS," "WARNING" or "CAUTION" to signs had little if any effect on drivers while the addition of instructions such as "NO STOPPING" or "MAINTAIN 15 IN FOG" was beneficial.

The numerical data collected from the delineation study indicated that raised reflective centerline and/or edgeline buttons did not significantly increase traffic flow stability in reduced visibility conditions due to fog. However, of the 58 subjects who were exposed to the delineation buttons, all 26 subjects of the high visibility and 27 of the 32 subjects of the low visibility study said the buttons were a helpful aid in maintaining their position on the roadway.

Study VI, the Cry Wolf Study, also produced some useful information. First, the more complex the system is, the more confidence the drivers put in the system's credibility. Each time a driver is exposed to false information by an advisory system (no matter how complex the system), he loses some confidence in the system. After a number of exposures to false or unrealistic information by a system, a driver will no longer respond to the system. In other words, for an advisory signing system to be useful, discretion must be exercised in the use of the system to insure driver credibility in the system.

Several items of interest were noted on the subject data forms. Ninety-seven percent of the subjects reported previous exposure to driving in fog. With regard to driving tactics used in fog, 46% of the subjects said they prefer to follow another vehicle in fog while 29% said they prefer to follow the pavement stripes whenever possible. Only five percent of the subjects said they would pull off the road and stop in dense fog.

In regard to lane used when driving in fog, 70% of the test subjects said they always drive in the right lane in fog while only 13% preferred the left lane. The remaining 17% did not have a preference.

A total of 232 test subjects stated that they encountered patchy fog on the test track. When asked how they responded to the less dense areas, 60% indicated that they increased speeds.

In a ranking of hazards associated with driving in fog, the subjects indicated that running into a stationary object or vehicle on the road was their number one concern, followed by being overtaken by a faster moving vehicle, running off the road, and overtaking a slower vehicle.

PHASE III - PRELIMINARY SYSTEM DESIGN

Several findings of this project are applicable in the design of a system to aid drivers during periods of reduced visibility due to fog. All of the techniques found to be useful in dealing with reduced visibility during this study can be directly applied to highway use.

For example, early studies showed that the maximum traffic flow instability occurred between 150 feet (45 m) and 500 feet (150 m) into the fog zone. It is reasonable to believe that on any given highway the maximum instability would also occur in this zone of the fog bank or between 150 feet (45 m) and 500 feet (150 m) into a dense patch of fog within a general fog zone. Likewise, we found that the first signs of an increase in flow instability in the unsigned case occurred approximately 750 feet (230 m) prior to the leading edge of the fog bank. One can also assume that this is where instability will begin when fog is encountered on a highway.

This project showed that certain types of sign messages produced favorable results while other messages had no effect, and active signing was determined to be more desirable than passive signs. This was also found to be true in a study entitled, "Driver Awareness of Highway Sites with High Skid Accident Potential" (1974). Also, signing within a fog zone, as well as outside the fog zone, is important. The utilization of a radio system to advise drivers also made positive changes in vehicular speed characteristics. The importance of system credibility was also demonstrated.

Using equipment presently available, it would be possible to develop a very sophisticated system to take into account all factors which are pertinent. But, due to costs involved, this would not be practical in most cases. An ideal system would include continuous traffic flow characteristic monitoring including incident detection throughout the reduced visibility or accident prone area. A more practical compromise would be to monitor traffic for each advisory sign location. By doing this the credibility of information displayed could be maintained.

Depending on how severe the reduced visibility problem is, on traffic volumes, on public interest, and on other factors, different locations would warrant different levels of funding. Therefore, different levels of systems would be required. Based on the results of this research project which were discussed, it is questionable whether a simple fixed message sign system would have any value in altering speed characteristics. Such a system, however, may have utility from a public relations standpoint, as well as from a legal standpoint. Care in choosing messages for this type of signing should be taken so as to maintain credibility. A possible message would be "WATCH FOR FOG." This type of signing should be covered during seasons of the year when fog does not exist if the occurrence of fog is seasonal. A fixed message signing system could be termed a Level 1 System.

A Level 2 signing system would also be relatively simple and would require the addition of flashers and a fog detector for each sign site. Possible messages to be displayed could be "SLOW - FOG WHEN FLASHING - NO STOPPING ON ROADWAY." Since signing for both Level 1 and Level 2 systems are warning types, the messages should be displayed with black legend on yellow diamond shaped boards to comply with the "Manual on Uniform Traffic Control Devices" (MUTCD). For a Level 1 or Level 2 signing system, it is desirable to have the signs installed in advance of the problem area. If the reduced visibility area being signed for with a Level 2 system is generally located in a particular area, the signing should be installed well in advance with the detector(s) located downstream in the reduced visibility area. In many cases, reduced visibility areas may vary considerably making it impossible to have the signs in advance of the fog at all times. For cases such as this, it may be desirable to locate detectors at the sign location.

A Level 3 system would include variable message and/or variable designated speed signing. There are a number of different types of variable message signs being manufactured which could be utilized in a Level 3 system and therefore no recommendations as to the type will be made. An example of a Level 3 type system could be the system of six variable message signs on I-5 near Albany, Oregon. These signs include yellow flashers, the Legend "SLOW" and "FOG" or "WRECK" along with the word "SPEED" and a designated speed. The speeds displayed include values of 10 MPH (16 km/h) to 50 MPH (80 km/h) in 10 MPH (16 km/h) increments. The signs are spaced approximately one mile apart and are mounted over the traffic lanes. In the Oregon system, the speed value posted is determined by the State Police based on judgment. During the fog season, a patrolman is on the signed section of the freeway at all times when fog is expected. The signs are manually operated. In a system such as this, much attention must be given to the operation of the system so that credible information is displayed. A Highway Advisor Radio (HAR) system could be included and may be beneficial in some Level 3 systems.

A Level 4 system would include variable message signs and could also include HAR to advise. It is anticipated that a Level 4 system would be utilized only on a section of highway which regularly experiences fog. As in the Level 3 system, drivers would be advised of the nature of the problem and of the proper actions to be taken such as speed and/or other instructions. Flashers should also be utilized to attract attention to the signs. Control of the signs could be automatic with a manual override. Since the proper posted speed depends on visibility, it would be necessary to have visibility detection equipment downstream from each sign and, also, to have the hardware and software to determine the various percentile speeds at one location for each sign. Signs could be spaced at one to two mile intervals with the first one in each direction an appropriate distance in advance of the problem area. Within the problem area, sign locations should be selected to advise drivers entering the highway at interchanges or intersections.

Both Level 3 and Level 4 systems may not be warranted except on four or more lane controlled access highways. A discussion of where various types of systems may be warranted will be included in a study entitled, "Effectiveness of Reduced Visibility Guidance Techniques," being conducted by Sperry Systems Management for the FHWA. That study will also include information concerning available equipment.

In some cases where a Level 3 or Level 4 system is not warranted based on visibility problems, the utilization of the system to handle other recurring problems or traffic control measures may make such a system worthwhile. Regardless of the function for which the systems are used, the information displayed should be concise and displayed in a timely manner to maintain credibility with drivers. It was found that messages such as "HAZARDOUS," "OBEY SPEED SIGNS," "CAUTION," and "WARNING" did not significantly change traffic flow characteristics in this study. The legend "END FOG ZONE" also did not appear to have any effect on vehicle speeds, but may be useful from a public relations standpoint.

For a Level 3 or 4 system, some possible messages could be those used in the Oregon I-5 system or messages similar to those used in signing scheme number 6 of the Signing Study (see Fig. 34 on page 66). There are other driver aids which may be helpful for guidance and/or public relations which may be included with any of the previously described systems. Reflectorized pavement markers did not appear to make a significant difference in vehicle speeds but may be helpful for guidance purposes. Low level illumination or illuminated pavement inset lights such as used on Afton Mountain in Virginia would also be expected to help guide drivers through reduced visibility problem areas.

Operations personnel including those responsible for maintenance should be involved in the design stage. In addition, to make a system acceptable and operate successfully, the public should be informed of what is being done and law enforcement personnel should be involved from the start. A cooperative effort with all interested or involved persons will help make the system operate successfully and make the system acceptable.

Appendix A
LITERATURE REVIEW

A study which was made on a rural New York freeway (K. Perchonok, 1969) collected data to investigate the effects of fog on drivers. Data was collected under night, dawn, and daylight conditions. Visual distance was measured as the maximum range at which lead vehicles could be seen. Of the three ways in which drivers are capable of manipulating their relationships with other vehicles (spacing, headway, and collision course time), none seemed to be influenced by fog. None of these changed systematically with the fog level. The one variable that was influenced by fog was vehicle speed.

The study shows that it appears that drivers are aware of fog as a hazard but they seem to either not know how to, or are not willing to, overtly respond in ways other than modest speed reductions. Data show that the speed reductions are insufficient to preclude excess overdriving. The problem is more severe under conditions of over-confidence associated with limited access highways.

A study by the California Division of Highways titled, "Detectors for Automatic Fog-Warning Signs," (W. R. Juergen, 1973) involved the installation of some changeable message signs on freeways. The report concluded that there was no evidence that speed was reduced in control zones while the signs were in operation warning of heavy fog ahead.

Another study by the California Division of Highways (T. N. Tamburri and D. J. Theobald, 1967) experimented with variable speed signs. The study concluded that:

1. Generally, fog by itself causes a reduction in speeds ranging from 5-8 MPH (8-13 km/h) for both the mean and 85th percentile speeds. The exceptions are during high volume daytime and low volume nighttime freeway operations when no or very small speed reductions are noted.
2. Generally, fog does not reduce the variability in speeds.
3. In all cases on the expressway, and only with low volumes on the freeways, posted speeds affected a further reduction in both the mean and 85th percentile speeds generally from 5-10 MPH (8-16 km/h).
4. Posted speeds reduced variability in speeds on the expressway but rarely on freeways.
5. Posted speeds of less than 35 to 40 MPH (55 to 65 km/h) have little additional effect in reducing speeds.
6. Drivers tend to drive at speeds higher than the posted safe speed.
7. Headways are not affected by fog or posted speeds.
8. In the limited testing done, very little difference was found in the effectiveness of regulatory and advisory speed limit signs.

The study also concluded that, of all of the devices and techniques tried on the highway, only the posting of speed limits has nay measurable effects on traffic. This effect was limited and occurred only when

traffic volumes were low or moderate. The effect was most pronounced at the lowest volumes and on the expressway. The posted speeds appeared to be less effective on freeways.

A third study by the California Division of Highways (D. J. Theobald, 1969) found after studying fog accidents that while most of the accidents occurred during the morning peak hours, they were usually in the off-peak direction. Accidents occurred in the peak direction also, but usually while traffic volumes were moderate or light. An explanation of this is that the off-peak accidents involved people going to work in the morning who were familiar with the road. The fact that they were traveling opposite of the peak flow allowed them to travel near the speed limits, thereby increasing the chance of not seeing an object in the fog soon enough. They also found that under most fog conditions and regardless of the control devices used, drivers drove faster than what was considered to be a safe speed. There is a minimum mean speed of between 35 and 40 MPH (55 and 65 km/h) that drivers observe even through they are experiencing very dense fog. Several times during radar speed checks at test sites, cars passed the observation point near or over the clear weather 65 MPH (105 km/h) speed limit.

A study by the National Transportation Safety Board on Reduced Visibility Accidents on Limited Access Highways (NTSB-HSS-72-4, 1972) observed that speeds in fog seem to be reduced more on conventional highways where drivers cannot maintain high speeds because of the curvature and alignment of the road. Also, the fact that vehicles can enter a conventional highway at many uncontrolled points required constant driver attention to the driving task. In contrast, the design features of interstate highways are such that drivers tend to drive at higher speeds with greater confidence. These greater speeds are reflected in increased accident severity.

A study for the Highway Research Board (W. H. Heiss, 1973) involved the use of a driving simulator for studying the reactions of drivers to fog. The driving simulator study substantiated the theory that under fog conditions the driver is more alert and his perception-reaction time is correspondingly shorter. Consequently, this study used a value of 1.8 seconds for perception-reaction time in the computation of safe stopping speeds rather than the AASHTO value of 2.5 seconds. This study concludes that the seriousness of a fog hazard can depend on the type of fog. For example, on the Pennsylvania Turnpike it has been reported that when there are large areas with generally uniform fog density, the drivers all tend to slow down somewhat, and the accident experience has not indicated that the fog is a serious safety hazard. Such fogs, however, may tend to induce a false sense of security leading to excessive speed on the part of many of the drivers. The area surrounding the Pennsylvania Turnpike is largely rural, with limited amounts of urban and suburban commuter-type traffic, so there may be less immediate urgency felt on the part of the drivers to arrive at their destinations at a specific time. It is therefore reasonable to expect that the behavior of the drivers and their reaction to signs and warning messages might be different. Also, when

drivers have previously been driving for a distance in fog on similar types of roads, it can be expected that they will show a greater resistance to change since the driving pattern will have been established. The same is also probably true during periods when fog is encountered on a frequent or regular basis.

A paper entitled "Some Principles for Communicating with Drivers Through the Use of Variable-Message Displays" (B. W. Stephens, 1971) analyzes the data from a 1966 fog study conducted by the California Division of Highways (Tamburri and Thoebald, 1967). The coefficient of variation of speeds (an inverse measure of traffic speed stability) was calculated.

This measure was then related to the posted speed limit as a function of fog-related sight distance. Speed data was used from an expressway with partial control of access and for a freeway for night and day conditions under high and low traffic volumes. Stephens concludes that where sufficient data exists, the results are practically unequivocal. There is an advisory speed at which maximum stability exists and that value differs depending on the visibility conditions. As visibility decreases, the posted speed at which the relative dispersion is minimal is lowered. In other words, lowering the posted speed a little below the prevailing speeds can improve traffic stability; lowering the posted speed too much will reduce stability. Each visibility distance condition has its own optimal value.

A paper entitled, "Minimizing the Hazard of Restricted Visibility in Fog," (R. N. Schwab, 1971) describes the effects of fog on driving and accidents. Based on a California fog study, Schwab concludes that variable message warning signs have little effect on mean operating speeds but that they do reduce speed variance when the sign is set at approximately the mean speed of traffic. If the signs are set much below the prevailing speed, a bimodal speed distribution results increasing the likelihood of rear-end collisions. Schwab speculated that part of the reason for these results may be the lack of reliability of the infromation provided by such signs in the past. Particularly, where manual changing of speed limits or folding advisory signing was required, the messages were often exposed long after the reduced visibility condition ended. Therefore, many drivers may have assumed that such signing is meaningless.

A report by the Oregon State Highway Division (1972) describes a research project involving the installation of variable message fog warning signs. The report states that the Oregon State Police regulate the use of the signs on a very strict basis. As a result, State Police indicate that driver observance of the signs is good. During periods of generalized Willamette Valley fog, police reports indicate that the speeds shown on the signs in this section are still being observed by vehicle operators many miles beyond the signed section.

A report by the National Transportation Safety Board on a multiple vehicle collision on the New Jersey Turnpike (NTSB-NAR-71-3, 1971) describes the effect of fog on drivers prior to the accident. The report

states that in going through successive fog patches in advance of the scene of the accident, all of which had been fairly short and light, some drivers may have been led into the belief that all of the foggy areas would be the same. Even when the visibility dropped in places to two to three car lengths, some drivers said that cars continued to pass them as though conditions ahead were clear. The existence of variable message speed signs set at 60 MPH (95 km/h) could have been a factor in the continuing speed of some vehicles, providing assurance that the fog was not sufficient to require speed reduction. All drivers interviewed claimed they had reduced their speeds, but it appears to have been a matter of degree, depending primarily upon how each driver evaluated the density and probable duration and hazard of the foggy area. Some drivers slowed moderately while others slowed considerably, and few came to a full stop. What to one driver was a prudent act - namely, to slow down immediately - brought disaster when the truck behind him did not slow down. The Safety Board determined that the probable cause of the multiple vehicle accident was the penetration by vehicles into an area of dense fog where the visibility was 20 to 50 feet (5 to 15 km) together with the varying rates of speed which prevented appropriate evasive action. Contributing factors were the absence of objective indicators of the density of the fog and inadequacy of the New Jersey Turnpike speed control system in that it failed to provide timely activation of speed reduction warning signs.

A study entitled, "Driver Awareness of Highway Sites with High Skid Accident Potential," (F. R. Hanscom, 1974) concluded that signing which incorporates flashing beacons which are activated only when the conditions require are more beneficial than passive signing. This study also concluded that it is important that the beacons only be activated during periods of need to maintain driver credibility in the signs.

TEST SITE FEATURES

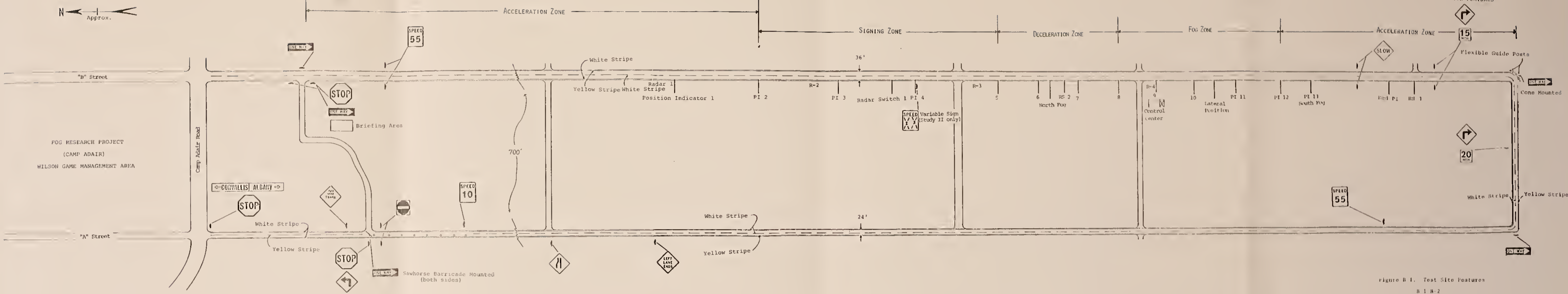


Figure B-1. Test Site Features

Appendix C
SUBJECT APPLICATION FORM

RESEARCH SUBJECTS NEEDED

MALE AND FEMALE DRIVERS OF ALL AGES

$21.52 for Approximately 3 Hours' Work
(Plus Mileage to and from Home)

The Oregon State Highway Division is conducting a research program in driver reactions to a variety of driving conditions. This research program will be conducted during the next 12 months at the E. E. Wilson Game Management Area off 99W between Corvallis and Monmouth.

All that will be required is to drive your car over our test highway a number of times. The tests will usually be conducted during early morning hours (approximately from 4:00 a.m. to 7:00 a.m.) so as not to interfere with normal work schedules. However, the tests must be conducted when weather conditions are favorable and some rescheduling may be required. Pay for participating in the program is $21.52 plus mileage. The tests will take approximately 3 hours. Both male and female drivers of all ages are needed.

The requirements to participate in this program are:

- You must have a valid driver's license and provide your own vehicle.
- Not presently a State employee (spouses can participate).
- You must be willing to meet our testing schedule.

If you are interested in participating in this program, fill out the attached form and mail it to the address shown. You will be contacted immediately with additional information.

-- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --

Name ______________________________ Age ________ Sex ______

Address ____

Telephone No. ____________________ Occupation ____________________

Mail to: F. D. Lane, Room 510, State Highway Building, Salem, OR 97310.

Appendix D
PROCEDURE FOR MANUAL ANALOG-DIGITAL CONVERSION

1. Use a pencil.

2. Record identification

   a) sequence number
   b) date of run
   c) car number
   d) run number
   e) type of run
   f) chart speed

3. Start Point

   a) Choose the first time reference line before the first tape switch mark.
   b) Mark graph on both top and bottom.
   c) Label inch marks above the curve for x-axis.

4. Major Data Points

   a) Locate each at the leading edge of each tape switch pulse.
   b) Using a ruler make a 2" line through the curve for each checkpoint.
   c) Label each interval (between checkpoints) with a circled number above the curve.
   d) Check for correct number of intervals and record number of tape switches used.
   e) Record the coordinates of the checkpoints in inches (x-axis) and MPH (y-axis).

5. Additional Data Points

   a) Choose any necessary additional points to properly describe the curve.
   b) Mark these points with a short line through the curve.
   c) Label the table with interval number and put in the coordinate values.

6. Record any remarks about the curve, data gathering, point selection, etc. that are not of the standard type.

7. Check Recorded Data

   a) Check checkpoints for increasing time values.
   b) Check the additional data points for increasing time values.

8. Date and initial both the chart and the table in the upper righthand corner.

Appendix E
ANALOG-DIGITAL DATA FORM

TITLE ______________________________

NUMBER OF TAPE SWITCHES ____________ CHART SPEED ____________

REMARKS:

PT	TIME	SPEED
1		
2		
3		
4		
5		

PT	TIME	SPEED
6		
7		
8		
9		
10		

PT	TIME	SPEED
11		
12		
13		
14		
15		

INTERVAL NO.		
PT	TIME	SPEED
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

INTERVAL NO.		
PT	TIME	SPEED
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

INTERVAL NO.		
PT	TIME	SPEED
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Figure E-1. Analog-Digital Data Form

Appendix F
ANALOG-DIGITAL ALGORITHM

PROGRAM DESCRIPTION

The computer program used for converting speeds vs. time data is available as an overlay on Oregon State University; CDC 3600.

The following items form the input to the program:

1) Title (48 character string)
2) Number of tape switches
3) Chart speed (optional, defaults to .5)
4) Time and speed at each tape switch
5) Time and speed at various points between the tape switches as required.

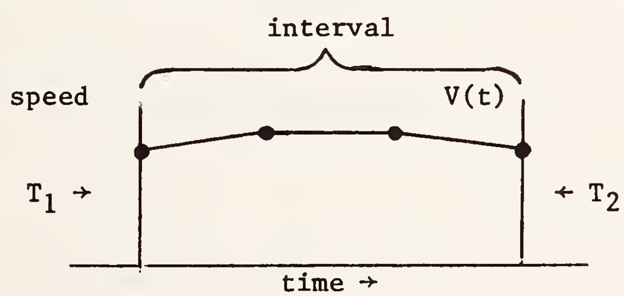
The output consists of a tabular listing of speed vs. distance and time. (A compressed version of the table is stored on a disk file.)

The program performs four major tasks:

1) Read deck and check for errors
2) Adjust speeds (if necessary)
3) Compute speeds at 25 ft. intervals
4) Produce table

Tasks 1 & 2 are straight forward and will not be described.

<u>Task 2</u>



---

1 ft = .305 m

T_1 and T_2 are tape switches. There are three non-independent measurements which must be reconciled within each interval.

1) Speed function V(t)
2) Time between tape switches T
3) Distance between tape switches d

We have

$$d = \int_{t_1}^{t_2} \gamma(t)dt \qquad \text{where } t_2 - t_1 = T$$

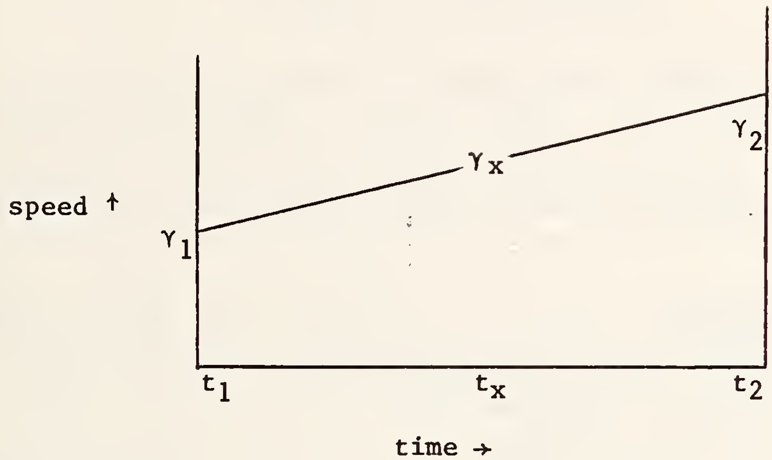
If V(t) is numerically integrated, the resulting distance will probably not be exactly equal to d. If not, one of the three measurements must be altered. V(t) is taken from radar readings which are not always reliable. D is exact (measured with a tape). T is from the strip chart, (the chart speed can be accurately measured). Thus, V(t) is the logical choice for modification.

The speed values are changed (in proportion to their magnitude) until the numerical integral is within 1%. This is done separately for each interval.

Task 3

Speeds at 25 ft. intervals are computed using linear interpolation.

1 ft = .305 m



Let (t_x, V_x) be the point located a distance d from (t_1, V_1).

$$\text{Let } m = \frac{V_2 - V_1}{t_2 - t_1}$$

Let $V(t)$ be the speed at any time t in $[t_1, t_2]$

We have then $V(t) = m(t - t_1) + V_1$

$$\text{Also } \int_{\tau 1}^{\tau x} \gamma(\tau)\, dt = d$$

Substituting

$$\int_{\tau 1}^{\tau x} [m\,(t - t_1) + V_1]\, dt = d$$

$$\frac{mt_x^2}{2} - mt_1t_x + V_1t_x + mt_1^2 - \frac{mt_1^2}{2} - V_1t_1 = d$$

$$\frac{m}{2}(t_x^2 - t_1^2) - mt_1t_x + V_1(t_x - t_1) = d$$

$$\frac{m}{2}(t_x^2 - 2t_1t_x + t_1^2) + V_1(t_x - t_1) = d$$

$$\frac{m}{2}(t_x - t_1)^2 + V_1(t_x - t_1) - d = 0$$

solving the quadratic

$$t_x - t_1 = \frac{-V_1 \pm \sqrt{2\ dm + V_1^2}}{m}$$

but

$$V_x = m(t_x - t_1) + V_1$$

substituting

$$V_x = \sqrt{2\ dm + V_1^2}$$

Using this result, the curve is merely step along. It should be noted that d is not 25 ft. after a data point is crossed.

---

1 ft = .305 m

Appendix G
SUBJECT INSTRUCTIONS

Study I - Normal Driving Conditions (Day and Night)

The State Highway Division is conducting a series of research programs to investigate driver reactions under various driving conditions. These include such things as weather, highway designs, signing, etc. Before we get into the program itself, let me show you the layout of the road system we will be using. This is a map of the area. We are presently located here with your cars parked along this road.

When we finish the briefing, we will ask you to go out and get into your cars and start from this point. You will proceed down this road, one at a time, to here. Turn right here and here, come back over this road to here, turn right again and come back to the starting point.

These roads are laid out as two lanes, or half of a divided highway. As with any freeway, there are posted speeds.. This section from here to here is posted for 55 MPH. The two curves here and here deserve special consideration. This curve is posted 15 MPH and this one 20 MPH. This section of road has a basic speed of 55 MPH down to about here where it tapers down to one lane. This section is posted 10 MPH.

The only thing that will be required of you is to drive this road system a number of times and to drive it in as natural manner as possible. We would like you to respond to these roads as you would any other, taking into account such things as road type, width, surface conditions, weather, etc. As far as the speeds go, we would like you to respond to them as you normally would again taking the same things into consideration. If the conditions warrant it and you normally drive a little over the posted speed, do so here. There will be no speed enforcement on these roads.

There are just two things I would like to caution you about. One is that these roads are just like any other roads in terms of hazards. While we are not going to create any really dangerous situations for you, whenever you are on highway, the possibility exists. If you do experience any unusual conditions, respond to them as you normally would. The other is the two curves. Special care should be taken in this area because the curves are sharp, especially the first one. This road extends on out and there are flexible rubber guide posts here. If you should get into any trouble on this curve, just go through them.

Mr. Smith will be located at the starting point. When he signals, start down the roadway; go all the way around and come back to this point. As each car moves out, I would like the rest to move up. When Mr. Smith indicates that we have finished the runs, I would like you to come back in here.

Are there any questions?

If that is all the questions, let us go ahead and get started. As a final reminder, let me mention the curves again; be careful on these. In addition, if at any time you have to stop while you are on the main roads or are unable to proceed for any reason, sound your horn and someone will come to assist you.

Study II Through Study VI

The State Highway Division is conducting a series of research programs to investigate driver reactions under various driving conditions. These include such things as weather, highway designs, signing, etc. Before we get into the program itself, let me show you the layout of the road system we will be using. This is a map of the area. We are presently located here with your cars parked along this road.

When we finish with the briefing, we will ask you to go out and get into your cars and start from this point. You will proceed down this road, one at a time, to here. Turn right here and come back over this road to here, turn right again and come back to the starting point.

These roads are laid out as two lanes on half of a divided highway in one direction. As with any highway, there are posted speeds based upon what we feel are safe speeds for the existing road conditions. Two that deserve special consideration are the curves here and here. This corner is posted 15 MPH and this 20 MPH. This section of the road tapers down to one lane and is posted 10 MPH. You may encounter other posted speeds.

The only thing that will be required of you is to drive this road system a number of times and to drive it in as natural manner as possible. We would like you to respond to these roads as you would any other, taking into account such things as road type, width, surface conditions, weather, etc. As far as the speeds go, we would also like you to respond to them as you normally would, again taking the same things into consideration. There will be no speed enforcement on these roads.

One thing I would like to caution you about is that these roads are just like any others in terms of hazards. While we are not going to create any really dangerous situations for you whenever you are on a highway the possibility exists. If you do experience anything unusual, respond to it as you normally would. On the other hand, I want to assure you that we are not going to have anything jump out in front of you or anything like that. Any conditions you encounter will be normal highway conditions.

Mr. Smith will be located at the starting point. When he signals, start down the roadway, go all the way around and come back to this point. As each car moves out, I would like the rest of you to move up. When Mr. Smith indicates that we have finished the runs, I would like you to come back in here.

Are there any questions?

If that is all the questions, let us go ahead and get started. As a final reminder, let me mention the curves again; be careful on these because they are sharp, especially the first one. This road extends out and there are flexible rubber guide posts along here. If you should get

into any trouble on this curve, just go through them.

If at any time you have to stop while you are on the main roads or are unable to proceed for any reason, sound your horn and someone will come to assist you.

Appendix H
SUBJECT DATA FORM

Study I - Normal Driving Conditions
(Day and Night)

Name ______________________________ Age ______ Sex __________

Address ______________________________

Occupation ______________________________

Driving experience (years) ______________________________

Present driver license issued from state of ______________________________

Average miles driven per year ______________________________

Type of vehicle used:

Make and model ______________________________ Year ______________

Ownership (check one) Owned __________ Borrowed ____________

If owned, how long? __________ years. How many miles have you driven it? __________ miles.

If borrowed, total miles you have driven it? __________ miles.

Vehicle condition (check appropriate condition for vehicle used in this study):

	Poor	Fair	Good
Lights			
Wipers			
Brakes			
Tires			
OVERALL			

Did you have any previous knowledge about this study? Yes _____ No _____ (check one)

If "YES," where did you hear about it?

Assuming "good weather," what speeds do/did you normally drive on: (fill in MPH)

Freeways such as Interstate 5 (assume old 70 MPH speed) ________ MPH

Freeways such as Interstate 5 (assume new 55 MPH speed) ________ MPH

Highways such as 99W (assume old Basic Rule 55 MPH speed)________ MPH

Highways such as 99W (assume new 55 MPH speed) ________ MPH

Assuming the type of weather we had today (not including the fog), what speeds would you normally drive on: (fill in MPH)

Freeways such as Interstate 5 (assume old 70 MPH speed) ________ MPH

Freeways such as Interstate 5 (assume new 55 MPH speed) ________ MPH

Highways such as 99W (assume 55 MPH speed) ________ MPH

Highways such as 99W (assume new 55 MPH speed) ________ MPH

Assuming you encountered the same fog condition you encountered today, what speeds would you drive on: (fill in MPH)

Freeways such as Interstate 5 (assume old 70 MPH speed) ________ MPH

Freeways such as Interstate 5 (assume new 55 MPH speed) ________ MPH

Highways such as 99W (assume 55 MPH speed) ________ MPH

Highways such as 99W (assume new 55 MPH speed) ________ MPH

Assuming everything you have experienced here today, do you feel you drove more cautiously than you normally would have if these roads were just a stretch of highway? (check one)

Yes ________ No ________

If "YES," give reason:

Prior to experiencing the fog, do you feel you were given enough exposure to the roads to become familiar with them? Yes _____ No _____(check one)

If "NO," how many more trips around the road would you liked to have had? __________ trips. (fill in number of trips)

How far from the fog were you when you first noticed there was fog on the road? __________ feet. (fill in the number of feet)

If you cannot estimate the distance in feet, where were you on the road when you first noticed the fog (i.e., halfway down the road; when I turned onto the road).

What is your previous experience with driving in fog? (check one)

None at all ______________

Occasionally (once or twice a year) ______________

Frequently (five to ten times a year) ______________

Other (explain or specify amount) ______________

If you have had previous experience in driving in fog, what types of roads did you usually encounter it on? (check one)

Freeways (such as Interstate 5) ___________

Highways (such as 99W) ___________

Other (specify) ___________

If you have had previous experience, what type of tactics do you usually use? (i.e., follow another car or truck in the right lane, drive in left lane at speed limit, pull to shoulder and stop, etc.)

What was your most noticeable reaction to the fog the first time you encountered it today?

Where did this reaction occur? (i.e., just before the fog bank, just as I entered it)

What happened to this reaction as the number of exposures to the fog increased? (check one and explain)

Remained the same ____________

Same reaction, but decreased in intensity ____________

Change to some others (explain) ____________

When driving through the fog here, which lane did you drive in? (check one)

Left ____________ Right ___________ Tried both ____________

Which did you prefer and why?

What would you estimate was your average speed through the fog? (fill in MPH) _____________ MPH.

Did you use wipers? No _______ Yes, on some runs ______ On all runs _____ (check one)

Did you use your lights? Yes _______ No ________ (check one)

If "YES," did you use: Low Beam ____ High Beam ____ Parking Lights___ (check any tried)

If you tried more than one, what percentage of the time did you use High _________ Low __________ Parking __________ (fill in percent)

Which beam did you prefer and why?

Did you tend to become more confident or less confident as the number of runs through the fog increased? (check one)

More confident __________

Less confident __________

No change between first to last run __________

If there was a change in confidence, to what do you attribute it?

Was the fog uniform throughout its length or did it tend to be patchy? (check one)

Uniform _________

Patchy _________

If patchy, what percent of the runs was it patchy? _________% (fill in %)

If patchy, what was your response to clear areas within the fog bank? (check one or specify)

None __________

Tended to speed up __________

Tended to slow down __________

Other (specify) ___________

What would you estimate the average distance you could see ahead of you in the fog was?

____________ feet (estimate in feet)

For the fog conditions you encountered, what do you feel would be a safe speed? (fill in MPH)

On this set of roads ______________ MPH

On an Interstate Highway such as I-5 ______________ MPH

On a highway such as 99W _______________ MPH

Do you have any general comments you would like to make concerning any aspects of this study or what you experienced today?

SUBJECT DATA FORM

Study II
POSTED SPEEDS

Name ________________________________ Age ________ Sex __________

Address ____

Occupation ____

Driving experience (years) _____________________________________

Present driver license issued from state of _____________________

Average miles driven per year __________________________________

Type of vehicle used:

Make and model __________________________ Year ______________

Ownership (check one) Owned ____________ Borrowed ____________

If owned, how long? __________ years. How many miles have you driven it? __________ miles.

If borrowed, total miles you have driven it? __________ miles

Vehicle condition (check appropriate condition for vehicle used in this study):

	Poor	Fair	Good
Lights			
Wipers			
Brakes			
Tires			
OVERALL			

1. Did you have any previous knowledge about this study? Yes ____ No ____ (check one)

   If "YES," where did you hear about it?

2. Assuming "good weather," what speeds do/did you normally drive on: (fill in MPH)

Freeways such as Interstate 5 (assume old 70 MPH speed) ________MPH

Freeways such as Interstate 5 (assume new 55 MPH speed) ________MPH

Highways such as 99W (assume old Basic Rule 55 MPH speed)________MPH

Highways such as 99W (assume new 55 MPH speed) ________MPH

3. Assuming you encountered the same fog condition you encountered today, what speeds would you drive on: (fill in MPH)

Freeways such as Interstate 5 (assume old 70 MPH speed) ________MPH

Freeways such as Interstate 5 (assume new 55 MPH speed) ________MPH

Highways such as 99W (assume old Basic Rule 55 MPH speed)________MPH

Highways such as 99W (assume new 55 MPH speed) ________MPH

4. Assuming you encountered the same fog conditions as you encountered today on a freeway such as I-5, how would you rank the following hazards (rank the four listed from one to four with one indicating the greatest hazard). If there are others you feel should be included, list them and include them in your ranking.

Hazard Type	Rank
Running off the road	________
Running into a stationary object or vehicle on the road	________
Overtaking a slower moving vehicle	________
Being overtaken by a faster moving vehicle	________
Other: (list and include in ranking)	
________________________	________
________________________	________
________________________	________

5. Assuming you encountered the same fog conditions as you encountered today on a highway such as 99W, how would you rank the following hazards (rank the four shown from one to four with one indicating the greatest hazard). If there are others you feel should be included, list them and include them in your ranking.

Hazard Type	Rank
Running off the road	______________
Running into a stationary object or vehicle on the road	______________
Overtaking a slower moving vehicle	______________
Being overtaken by a faster moving vehicle	______________
Others: (list and include in ranking)	
____	______________
____	______________
____	______________

6. When you encounter reduced speed zones on highways, do you usually: (check one)

Comply with the speed ______________

Tend to go faster than the required speed ______________

Tend to go slower than the required speed ______________

If faster or slower, how many miles per hour faster or slower?
____________MPH (fill in MPH)

Reason (i.e. posted speeds are generally slower than are required, I tend to be cautious, etc.)

____

____

____

____

7. Assuming everything you have experienced here today, do you feel you drove more cautiously than you normally would have if these roads were just a stretch of highway? (check one)

YES ______________ NO ______________

If "YES," give reason: ____

____

____

8. In general, do you feel the speeds which were posted just before the fog were reasonable for the conditions you encountered? (check one)

YES ____________ NO ______________ SOMETIMES _____________

If no or sometimes, can you identify the runs on which they were not, (i.e. none of them, first and third, etc.)

____

____

____

____

____

On the runs that were not reasonable, were they too high or too low? (indicate the run number and whether the speed was too high or too low)

____

____

____

____

____

9. How far from the fog were you when you first noticed there was fog on the road? ___________ feet. (fill in the number of feet)

10. If you cannot estimate the distance in feet, where were you on the road when you first noticed the fog (i.e., halfway down the road, when I first turned onto the road)?

____

____

____

11. On your first fog run, did you notice the change in the posted speed on the sign just before the fog? (check one)

YES __________ NO __________

Did you attempt to slow to that speed? (check one)

YES __________ NO __________

Did you attempt to maintain that speed through the fog? (check one)

YES __________ NO __________

If no, why not?

____

____

____

12. What is your previous experience with driving in fog? (check one)

None at all __________

Occasionally (once or twice a year) __________

Frequently (five to ten times a year) __________

Other (explain or specify amount) __________

13. If you have had previous experience in driving in fog, what types of roads did you usually encounter it on? (check one)

Freeways (such as Interstate 5) __________

Highways (such as 99W) __________

Other (Specify) ____________________

14. If you have had previous experience, what type of tactics do you usually use? (i.e., follow another car or truck in right lane; drive in left lane at speed limit, pull to should and stop, etc.)

____

____

____

____

15. What was your most noticeable reaction in terms of a feeling or emotion the first time you encountered the fog (i.e., uncertainty, scared, etc.)?

____

____

A. Where did this reaction occur (i.e., just before the fog bank, just as I entered it, etc.)?

____

____

B. What happened to this reaction as the number of exposures to the fog increased? (check one or explain)

Remained the same __________

Same reaction, but decreased in intensity __________

Changed to some others (explain) ____________________

____

16. What was your most noticeable driving response to the fog the first time you encountered it (i.e., none, tried to slow down as fast as possible, tried to slow down gradually, etc.)

____

____

____

A. When did this reaction occur (i.e., just before the fog bank, just as I entered it, etc.)?

____

____

B. What happened to this reaction as the number of exposures to the fog increased? (check one or explain)

Remained the same ____________

Same reaction, but decreased in intensity ____________

Changed to some others (explain) ____________________

____

17. When driving through the fog here, which lane did you drive in? (check one)

Left ____________ Right ____________ Tried both ____________

Which did you prefer and why? ____________________________

____

____

18. Did you tend to use the painted lines to guide you on through the fog? (check one)

YES ____________ NO ____________ SOMETIMES ____________

If "YES" or "SOMETIMES," which line did you usually rely on? (check one)

YELLOW ____________ DASHED WHITE ____________ SOLID WHITE ________

If you tried more than one, which did you prefer and why?

____

____

____

19. Did you experience difficulty in maintaining your position on the road when driving through the fog (i.e., did you find yourself in another lane or in a position on the road other than where you thought you were or wanted to be)? (check one)

YES ________ NO ________ SOMETIMES ________

If "YES" or "SOMETIMES," did you tend to be: (check one)

Right of where you thought you were ________

Left of where you thought you were ________

Sometimes right and sometimes left ________

How frequently or on which runs did this occur (fill in run numbers if you can or estimate frequency)?

____

____

Where did this tend to occur (on the entire length, in the middle, towards the end, etc)?

____

____

20. What would you estimate was your average speed through the fog? (fill in MPH)

________MPH

21. Did you use wipers? No ________ Yes, on some runs ________
(check one)
On all runs ________

22. Did you use your lights? Yes ________ No ________ (check one)

If "YES," did you use: Low beam ________ High beam ________
(check any tried)
Parking lights ________

If you tried more than one, what percentage of the time did you use
High ________ Low ________ Parking ________
(fill in percent)

23. Did you tend to become more confident or less confident as the number of runs through the fog increased? (check one)

More confident ___________

Less confident ___________

No change between first to last run _____________

If there was a change in confidence, to what do you attribute it?

____

____

____

24. Was the fog uniform throughout its entire length or did it tend to be patchy (check one)

Uniform __________ Patchy ____________

If patchy, what percent of the runs was it patchy?______%(fill in%)

If patchy, what was your response to clear areas within the fog bank? (check one or specify)

None ______________

Tended to speed up _____________

Tended to slow down _____________

Other (specify) ____

25. What would you estimate the average distance you could see ahead of you in the fog was? __________ feet (estimate in feet)

26. For the fog conditions you encountered, what do you feel would be a safe speed? (fill in MPH)

On this set of roads ____________MPH

On an Interstate Highways such as I-5 _____________MPH

On a highway such as 99W _____________MPH

27. Do you have any general comments you would like to make concerning any aspects of this study or what you experienced today?

SUBJECT DATA FORM FOR STUDY II WAS
MODIFIED AS FOLLOWS FOR STUDY III

Item 8 was modified to read as follows:

In general, do you feel the speed which was posted just before the fog was reasonable for the conditions you encountered? (check one)
YES __________ NO ___________
If no, was it too high or too low? (check one)
Too high __________ Too low __________
What do you feel would have been a more reasonable speed?
___________MPH (fill in speed)

Item 15B was deleted form the form.

Item 16B was deleted from the form.

The following was added to the form:

Did you encounter other traffic on the road?
YES _________ NO ___________
If yes, what type? (check)
Vehicle ahead of me ________ Vehicle behind me ________ Both _________

Where did you encounter? (check)
Before fog ___________ In fog ___________
Did the other traffic cause you concern or influence your driving in any way? (specific and explain)

Item 21 was modified to read as follows:

Did you use wipers? (check one)
YES __________ NO ___________

Item 23 was deleted from the form.

Item 24 was modified to read as follows:

Was the fog uniform throughout its length or did it tend to be patchy?
(check one) Uniform ___________ Patchy ___________
If patchy, what percent of the runs was it patchy?
__________% (fill in %)
If patchy, what was your response to clear areas within the fog bank? (check one or specify)

NONE _________ SPEED UP __________ SLOW DOWN ___________ OTHER _________

SUBJECT DATA FORM FOR STUDY II WAS
MODIFIED AS FOLLOWS FOR STUDY IV

Item 8 was modified to read as follows:

In general, do you feel that the speed which was posted before the fog was reasonable for the conditions you encountered? (check one)

YES ________ NO __________

If no, was it too high or too low? (check one)

Too high _________ Too low __________

What do you feel would have been a more reasonable speed?

____________MPH (fill in speed)

Item 8 was also modified as follows for the Radio test:

In general, do you feel that the speed which was broadcast before the fog was reasonable for the conditions you encountered? (check one)

YES __________ NO __________

If no, was it too high or too low? (check one)

Too high __________ Too low __________

What do you feel would have been a more reasonable speed?

____________MPH (fill in the speed)

Item 11 was deleted and the following was added:

When the fog sign was flashing, did you attempt to slow to the indicated speed?(check one)

YES ___________ NO ___________

Did you attempt to maintain that speed through the fog? (check one)

YES __________ NO __________

If no, why not? ______________________________________

Item 15B was deleted from the form.

Item 16B was deleted from the form.

Item 21 was modified to read as follows:

Did you use wipers? (check one)

YES___________ NO __________

Item 23 was deleted from the form.

Item 24 was modified as follows:

Was the fog uniform throughout its length or did it tend to be patchy? (check one) Uniform ________ Patchy __________

If patchy, what was your response to clear areas within the fog bank? (check one or specify)

NONE ________ SPEED UP _________ SLOW DOWN _________ OTHER ______

SUBJECT DATA FORM FOR STUDY II WAS
MODIFIED AS FOLLOWS FOR STUDY V

Item 8 was modified to read as follows:

In general, do you feel that the speed which was posted before the fog was reasonable for the conditions you encountered? (check one)

YES ________ NO _________

If no, was it too high or too low? (check one)

Too high __________ Too low _________

What do you feel would have been a more reasonable speed?

______________ MPH (fill in speed)

Item 11 was deleted and the following added:

When the fog signs were flashing did you attempt to slow to the indicated speed? (check one)

YES __________ NO ___________

Did you attempt to maintain that speed through the fog? (check one)

YES __________ NO ___________

If no, why not? ____

Item 15 B was deleted and the following added:

What happened to this reaction as the number of exposures to the fog increased? (check one or explain)

Remained the same __________

Same reaction, but decreased in intensity _________

Changed to some others (explain)

Item 16B was deleted and the following added:

Did you feel the fog signing was adequate for the conditions you encountered here tonight?

YES __________ NO ___________

If no, explain (i.e. too many signs, too many flashing lights, not enough signs, etc.).

Item 23 was deleted from the form.

The following was added to the form:

Did you find the reflective center line and edge line buttons helpful in the fog?

YES__________ NO ___________

SUBJECT DATA FORM FOR STUDY II WAS
MODIFIED AS FOLLOWS FOR STUDY VI

Item 8 was modified to read as follows:

In general, do you feel that the speed which was posted before the fog was reasonable for the conditions you encountered? (check one)
NO ____________ YES ____________
If no, was it too high or too low? (check one)
Too high __________ Too low __________
What do you feel would have been a more reasonable speed?
____________ MPH (fill in speed)

Item 11 was deleted and the following was added:

When the fog signs were flashing, did you attempt to slow to the indicated speed? (check one)
NO__________ YES __________
Did you attempt to maintain that speed through the fog? (check one)
NO__________ YES __________
If no, why not? ____________________________

Item 15B was deleted from the form.

Item 16B was deleted and the following was added:

Did you feel the fog signing was adequate for the conditions you encountered here tonight?
NO__________ YES ___________
If no, explain (i.e. to many signs, too many flashing lights, not enough signs, etc.).

Item was deleted from the form.

Appendix I
RESULTS OF SUBJECT DATA FORMS
STUDY I
NORMAL DRIVING

Age and sex distribution of subjects:

Age	Male	Female	Total
<20	3	2	5
20 - 29	11	7	18
30 - 39	4	7	11
40 - 49	2	11	13
50 - 59	3	1	4
Total	23	28	51

Driving experience (years):

$\overline{X}$	(Average)	16.5
σ	(Standard Deviation)	10.8
R	(Range)	1 - 40

Average miles driven per year:

$\overline{X}$	9,300
σ	7,432
R	100 - 32,000

Prior knowledge of study:

6 Had prior knowledge of study
45 Had no prior knowledge of study

Speeds that subjects say they normally drive, assuming "good weather":

Freeways such as Interstate 5
(with old 70 mph speed)

$\overline{X}$ = 66.67
σ = 6.38
R = 50 - 80

Freeways such as Interstate 5
(with new 55 mph speed)

$\overline{X}$ = 55.58
σ = 4.56
R = 45 - 65

Highways such as 99W
(with old Basic Rule 55 mph speed)

$\overline{X}$ = 54.27
σ = 5.27
R = 30 - 65

Highways such as 99W
(with new 55 mph speed)

$\overline{X}$ = 53.21
σ = 5.27
R = 30 - 60

Speeds that subjects say they would normally drive when weather conditions are same as they were day of test:

Freeways such as Interstate 5
(with old 70 mph speed)

$\overline{X}$ = 64.61
σ = 6.54
R = 40 - 65

Freeways such as Interstate 5
(with new 55 mph speed)

$\overline{X}$ = 55.21
σ = 4.90
R = 40 - 65

Highways such as 99 W
(with old Basic Rule 55 mph speed)

$\overline{X}$ = 53.59
σ = 4.13
R = 45 - 60

Highways such as 99W
(with new 55 mph speed)

$\overline{X}$ = 53.21
σ = .02
R = 45 - 60

Speeds subjects say they would drive if they encountered same fog condition as during test:

	70 MPH (I-5)	55 MPH (I-5)	Basic (99W)	55 MPH (99W)
$\bar{X}$ =	15.00	13.75	12.81	12.81
σ =	9.66	7.19	6.57	6.57
R =	0-40	5-30	5-25	5-25
$\bar{X}$ =	13.33	13.33	10.83	10.83
σ =	10.94	10.94	10.62	10.62
R =	0-40	0-40	0-40	0-40
$\bar{X}$ =	26.67	25.42	22.08	22.08
σ =	13.71	13.05	10.33	10.33
R =	5-45	4-45	5-45	5-45
$\bar{X}$ =	33.64	32.27	28.18	28.18
σ =	12.27	10.09	10.55	10.55
R =	20-60	20-55	20-55	20-55

Fourty-four subjects said that they did not drive more cautiously during test runs than they would have if these had been just any stretch of highway. Seven subjects said that they had driven more cautiously. All of the subjects said that they were given enough exposure to the roads prior to experiencing the fog.

Distance from fog when first noticed there was fog on the road:

$\bar{X}$ = 285.0 Feet
σ = 261.85 Feet
R = 0-1,000 Feet

Relative position on road to fog when first noticed fog on road:

Halfway to fog	8
Over halfway to fog	2
Fairly close to fog	1
In fog	1

Previous experience with driving in fog:

None at all	26
Very little (once or twice a year)	22
Frequently (five to ten times a year)	1
Other (explain or specify amount)	

Types of road fog has been experienced on:

Freeways (such as Interstate 5)	22
Highways (such as 99W)	38
Residential	6
Country	3
Coastal	2
Mountain	3

Driving tactics usually used in fog:

Follow other vehicle	20
Follow pavement stripes	10
Follow center line stripe	5
Follow right shoulder stripe	4
Follow left shoulder stripe	3
Watch for sight posts	3
Drive in right lane	10
Drive in left lane	3
Drive down middle	2
Drive slower	13
Pull off and stop	4
Dim headlights	5
Drive with windshield wipers on	1
Drive with head out of window	3
Watch edge of highway	1
Drive normal	1

Most noticeable reaction to fog the first time it was encountered during test runs:

Emotional Reactions		Driving Reactions	
Amused	1	Brought car to complete stop	2
Helplessness	1	Slowed down	21
Gasp	1	Drove with extreme care	7
Surprise	7		
Fear	1		
Spooky	1		
Scared to death	1		
Concern	1		
Fright	1		

Where this reaction occurred:

When first seen	2
Just before entering	18
Just as entered	21
When in it	8

What happened to reaction as exposures to fog increased:

Remained the same	13
Same reaction, but less intense	23
Became used to condition	7
Felt more sure of what was asked	3
Started to slow-up before fog bank	3

Lane used when driving through fog:

	100	200	300	400	500	Total
Right	10	8	11	10		39
Left	3	1				4
Both	3	3				6

Estimated speed in fog:

	100	200	300	400	500
$\overline{X}$	10.0	9.71	17.33	17.94	
σ	5.97	6.90	3.33	7.34	
R	2-22	2-30	5-20	5-33	

Use of windshield wipers:

All of the time	24
Some of the time	23
None of the time	4

Use of headlights (night conditions):

Low-beam	31
High-beam	1
Tried both	19
Parking lights	2
Emergency flasher	1

Headlight beam preferred:

Low-beam	44
High-beam	6

Change in confidence as number of exposures to fog increased:

More confident	35
Less confident	2
No change	13

Response when asked whether fog was uniform or patchy:

Uniform	14
Patchy	37
% of patchy runs	45%

Response to clear areas within the fog bank:

Keep same speed	3
Speed up	24
None	1

Estimated visual range in fog:

	100	200	300	400
$\bar{X}$	10.0	29.0	13.0	50.0
σ	8.42	41.55	14.0	46.98
R	2-30	3-150	3-30	10-150

Driver estimated safe speed for conditions encountered on this set of roads:

	100	200	300	400
$\bar{X}$	8.8	11.0	14.3	21.1
σ	4.95	8.80	5.87	8.37
R	2-20	2-35	5-25	10-35

On interstate freeway such as I-5:

	100	200	300	400
$\bar{X}$	9.6	14.7	17.7	28.6
σ	6.03	10.10	9.53	10.98
R	0-20	2-40	10-40	15-40

On highway such as 99W:

	100	200	300	400
$\bar{X}$	8.4	11.6	14.3	22.3
σ	5.47	9.29	5.47	7.86
R	0-20	0-35	5-25	10-35

Subjects general comments on any aspect of study, or things experienced during tests:

Interesting - I feel it was unexpected on my part. The fog was real, the conditions were real. I feel I drove as I would in a real situation.

I would not attempt to drive in such conditions if at all possible. I had no idea where the lines or shoulders even were when going through the fog, until it let up a little.

I definitely feel that the white lines are hard to see in the heavy fog.

In areas prone or a tendency for fog conditions, the use of highly reflective paint or reflectors embedded in road surface or spaced by the side of the road would be an aid in guiding through fog.

I have never encountered fog like that (so thick) under normal driving conditions. People lose respect after running the same course so many times.

What a way to make a buck!

Center line closer.

Was interesting and would like to participate again if possible.

Just hope I was helpful.

I enjoyed being asked to participate. The Highway personnel were very pleasant and helpful.

Find a painted line that can be seen in fog. I had a bad time seeing the line.

I think it's a bunch of bull sh__ and that because I think I could verify this statement but see no purpose it doing such!

It's excellent when you are trying to improve the roads.

Interesting experience. I enjoyed doing it.

Valuable data could be collected on drivers and cars.

If I were able to help at all I am happy to have been of service.

I would be interested in test results from the study.

My greatest anxiety was being sure that I did not miss the turn - though the fog might go all the way on a run. Still had the feeling of defensive driving in this respect. Keeping in motion also seem to be defensive in attempt to keep from being rear-ended.

It was interesting and I enjoyed it. It is nice to know the Highway Division is concerned about people's reactions to hazardous driving conditions and maybe after a completion of this testing they will be more able to come up with safety precautions.

More road hazards would have provided you with additional useful information.

I'm glad the curve was fog free!

At one point, a bank of lights on the right went on when I got too close to the right. I think that's a great safety device for frequently fogged in areas.

Would the results change drastically if the experiment was run in the day?

I would be interested to have my reaction shown to me.

If possible, use more time for each group with different types of conditions in cold weather, snow, ice, hail, etc. and heavy rain.

If the fog was put at a different place, about halfway through, one would not become so programmed to it.

I've never thought about or really considered what speed I go when I meet road conditions where I cannot see so my estimates may be very off.

STUDY II
POSTED SPEEDS

Age and sex distribution of subjects:

Age	Male	Female	Total
<20	9	4	13
20 - 29	20	30	50
30 - 39	2	12	14
40 - 49	3	8	11
50 - 59	4	5	9
60 - 69	5	1	6
70 above	1	1	2
Total	44	61	105

Driving experience (years):

$\overline{X}$	(Average)	16.0
σ	(Standard Deviation)	13.65
R	(Range)	<1 to 65

Prior knowledge of study:

24 Had some prior knowledge of study
81 Had no prior knowledge of study

Speeds that subjects say they normally drive, assuming "good weather":

Freeways such as Interstate 5
(with old 70 mph speed)

$\overline{X}$ = 67.90
σ = 5.73
R = 52.5 - 80

Freeways such as Interstate 5
(with new 55 mph speed)

$\overline{X}$ = 56.24
σ = 3.28
R = 50 - 63

Highways such as 99W
(with old Basic Rule 55 mph speed)

$\overline{X}$ = 55.56
σ = 5.42
R = 40 - 70

Highways such as 99W
(with new 55 mph speed)

$\overline{X}$ = 54.41
σ = 4.19
R = 40 - 65

Speeds that subjects say they would drive if they encountered same fog condition as during test:

	70 MPH (I-5)	55 MPH (I-5)	Basic (99W)	55 MPH (99W)
$\overline{X}$ =	19.88	18.73	16.0	16.0
σ =	12.92	11.78	10.35	10.35
R =	0-55	0-55	0-45	0-45

Subject responses to ranking road hazards from 1 to 4 (1 being the most hazardous) while being in fog on a freeway such as I-5:

	$\overline{X}$	σ
Running off the road	2.47	1.13
Running into a stationary object or vehicle on the road	2.10	1.12
Overtaking a slow moving vehicle	2.87	1.06
Being overtaken by a faster vehicle	2.58	1.15

Other possible hazards in fog that subjects mentioned:

Auto trouble	7
Panic	5
Animal in road	2

Subject responses to ranking road hazards from 1 to 4 (1 being the most hazardous) while being in fog on a highway such as 99W:

	$\overline{X}$	σ
Running off the road	2.20	1.13
Running into a stationary object or vehicle on the road	2.12	1.13
Overtaking a slower moving vehicle	3.06	1.07
Being overtaken by a faster vehicle	2.76	1.05

Other possible hazards in fog that subjects mentioned:

Auto trouble	1
Panic	5
Animal in road	5
Being hit in the side	2

Reaction to reduced speed zones when encountered:

Comply with the speed	63
Tend to go faster than the required speed	42
Tend to go slower than the required speed	5

Faster than required speed by: $\bar{X}$ 6.84
σ 2.69

Slower than required speed by: $\bar{X}$ 11.88
σ 7.74

Reasons for exceeding speeds in reduced speed zones:

Reduced speeds are generally slower than need be:	26
Familiar with roads:	3
Let car slow down by itself:	3

Reason for driving slower than posted speed in reduced speed zones:

Extra cautious

Seventy-seven subjects said that they did not drive more cautiously during test runs than they would have if these had been just any stretch of highway. Twenty-six subjects said that they had driven more cautiously.

Reasons for driving more cautiously than normal:

Being a test situation	10
Nighttime	4
Not completely familiar with road	3

Response to whether or not posted speeds were reasonable:

Reasonable	53
Unreasonable	13
Sometimes reasonable	36

Unreasonable posted speeds:

Too high	37
Too low	7
Both	2

Distance from fog when first noticed there was fog on the road:

$\overline{X} = 271.68$
$\sigma = 250.76$
$R = 3 - 1{,}200$

Subject response as to whether change of speed sign was noticed on first fog run:

Was noticed	176
Was not noticed	16

One hundred sixty subjects stated that they did attempt to slow down to the posted speed. Nineteen subjects stated that they made no attempt.

Twenty-six subjects stated that they did attempt to drive through the fog at the posted speed. Seventy-three subjects stated that they did not.

Reasons why no attempt was made at driving through fog at posted speed:

Drove slower	43
Drove faster	2
Watched road, not speedometer	12

Previous experience with driving in fog:

None at all	2
Very little (once or twice a year)	54
Frequently (five to ten times a year)	40
Over ten times a year	3
All the time	2

Types of road fog has been experienced on:

Freeways (such as I-5)	40
Highways (such as 99W)	68
Country roads	11
City streets	7
Coastal roads	5
Back roads	4
Residential roads	2
Mountain roads	1

Driving tactics usually used in fog:

Follow another vehicle	56
Slow down	19
Stay in right lane	17
Dim headlights	10
Pull over and stop	8
Watch pavement stripes	25
Stay in right lane	18
Travel at consistant speed	1

Most noticeable reaction to fog the first time it was encountered during test runs:

EMOTIONAL REACTIONS		DRIVING REACTIONS	
Uncertainty	46	Caution	9
Caution	8	Slow down	2
Afraid	13		
Uptight	4		
Startled	1		
Alert	3		
Feeling lost	3		
Spooky	1		
Surprise	6		
Amazed	1		
Panicked	1		
Mad	1		
Worried	2		

Where this reaction occurred:

As soon as fog was seen	2
Just before entering fog	19
Just as entered fog	47
In the fog bank	13
Halfway through the fog	9
When could not see road	1

What happened to reaction as exposures to fog increased:

Remained the same	31
Same reaction, but less intense	48
Became more confident	13
Became frightened	3
Same reaction, but more intense	3

Most noticeable driving response to fog the first time it was encountered:

Slow down gradually	68
Slow down quickly	25
Watch pavement stripes	4
Stopped	4
Dim headlights	1

Lane used when driving through fog:

Right	63
Left	13
Both	30

Reasons for lane preference:

RIGHT -	Used to right lane	26
	Slow traffic belongs in right lane	5
	Can see center line and reflectors easier	7
	Can see white stripe on right easier	6
LEFT -	Yellow line can be seen easier	23

All of the people used the pavement stripes to help being guided through the fog.

STRIPES USED -	Solid white	51
	Dashed white	51
	Yellow	23
STRIPES PREFERRED -	Solid white	15
	Dashed white	13
	Yellow	17

Reasons for stripe preference:

Yellow seemed more visible	13
Solid white more visible	8
Dashed white more visible	3
Dashed white seen out of driver side window	4

Difficulty maintaining position on the road:

Was difficult	51
Was not difficult	14
Sometimes difficult	37

When drivers did have difficulty they tended to be:

Right of where they thought	11
Left of where they thought	55
Sometimes right, sometimes left	22

Difficulty maintaining position occurred:

Once	29
Twice	18
Three times	6
Four times	4
Five times	2
Six times	1
Occasionally	4
Most runs	1
All runs	12

Location where difficulty of maintaining position occurred:

Shortly after entering fog	8
Beginning to middle fog	5
Middle of fog zone	52
In very dense fog	5
Middle to end of fog	2
Near the end of fog zone	7
Entire length of fog	7

Estimated average speed through fog:

$\overline{X}$	12.04
σ	8.01

Use of windshield wipers:

During all of the runs	32
Some of the runs	48
None of the runs	24

Use of headlights:

	LOW BEAM	HIGH BEAM
$\overline{X}$	= 92.0 %	32.0 %
σ	= 19.68%	34.37%
Sample Size	= 99	31

Three people used parking lights 1% of the time.

Change in confidence as number of exposures to fog increased:

More confident	72
Less confident	10
No change	16

Change in amount of confidence attributed to:

Became familiar with road	17
Became familiar with situation	40

Response when asked whether fog was uniform or patchy:

11 people said fog was patchy 100% of the time
3 people said fog was patchy 90% of the time
7 people said fog was patchy 80% of the time
8 people said fog was patchy 75% of the time
4 people said fog was patchy 60% of the time
10 people said fog was patchy 50% of the time
1 person said fog was patchy 40% of the time
6 people said fog was patchy 30% of the time
4 people said fog was patchy 25% of the time
6 people said fog was patchy 20% of the time
3 people said fog was patchy 15% of the time
3 people said fog was patchy 10% of the time
3 people said fog was patchy 5% of the time
23 people said fog was patchy 0% of the time

Reaction to clear areas within fog banks:

Increase speed	43
Maintain speed	9
Try to get bearings	3
No reaction	43

Estimated visual range in fog:

$\bar{X}$ = 10.35
σ = 8.21

Driver estimated safe speed for conditions encountered on this set of roads:

	100	200	300
$\bar{X}$ =	7.74	12.44	14.9
σ =	3.53	7.36	6.07
R =	2.5-15	1-40	5-25

On Interstate Freeway such as I-5:

	100	200	300
$\bar{X}$ =	12.26	18.65	20.53
σ =	6.61	11.41	10.4
R =	2.5-25	1-40	5-45

On Highway such as 99W:

	100	200	300
$\bar{X}$ =	10.6	14.13	16.3
σ =	6.12	8.6	7.93
R =	2.5-25	1-40	5-40

Subjects general comments on any aspect of study, or things experienced during tests:

It was very interesting. I was not totally clear on use of lanes, and using parking lights to drive didn't occur to me (though I've driven in Italy, where it is illegal at night to use anything but parking lights). Not knowing much about what the test was for or what it would be like made me a little tense (and very curious). After the first run of fog I expected to possibly encounter other highway hazards or conditions.

Interesting and new respect for fog.

I gained more respect for posted speed signs. I learned something of my driving habits.

Very interesting.

My only comment is that the yellow lines are far better.

Makes me want to be careful in fog conditions when driving in future.

I think this was not typical of fog driving conditions because we realized that no one would be coming along behind us or ahead of us. This is what is terrifying about fog, not knowing what to expect in the way of other drivers reactions.

Could be more variations or muliple changes in posted speeds on the course.

An interesting study and very worthwhile from every standpoint.

A good lesson.

It was an excellent experience and I appreciated the opportunity to attend the session.

It would be a good study for the public to partake in so that they can experience encountering fog. Should publicize it. Should be given in the late evening (11 - 1 am).

It was a good test and study.

It was very realistic.

I hope I don't have to drive in fog like that very much.

I hope my husband is driving if we ever run into this again.

It was an experience.

I have not encountered fog as thick as I did here.

I would like to be informed of the study's results.

I think that I could have stayed in the right lane if the center line were solid.

I hated the damn thing, but if it will help, why not!

Very interesting and well conducted.

I was sleepy due to the early hour.

Why only one hazard? I encountered more than fog when driving. Tell us what monitoring devices are being used and give us a sense of belonging to the test. I personally would like to see the results.

I think it was a good test.

It's a conversation piece (but I'll keep quiet until testing's over).

It was very surprising at the time.

Well done, Gents.

The study was too boring for participant. Too much time lapsed between runs - had to start and stop engine too often. Should tell us to bring a book or something to pass the time (we didn't know what to expect).

Driving lines on both sides of lane make fog easier to handle.

The side lines are helpful, also those things that they put on the white lines would be helpful.

I feel center reflector would reduce lane drift, and would lessen the tendency to follow another vehicle too closely. In extremely wet weather (in the absence of fog) the center lines - solid and broken are much more difficult to see.

Center line should be solid line where fog conditions occur.

I had thought a yellow line would be better to follow in fog, but if there was a yellow line there, I didn't see one.

The speeds are too fast for the density of the fog.

Why is the test conducted at this time period as opposed to 9 PM to 12 PM? Just curious.

Good test, I found out I am now with only one headlight.

Quite interesting - I stayed awake the whole time.

Interesting as to reaction - seemed same as any other time when circumstances were similar.

I wish it could take place earlier in the evening, but otherwise it was pretty interesting.

I think highways should be temporarily closed and motorists asked to pull over if fog is as thick as it was on some runs.

Wonder how this will be used in regards to general public.

I for some reason, did not think of this as a 2-way road, thus did not try the yellow stripe.

I feel you need a better solid white line on shoulders (perhaps small reflectors).

STUDY III
INFORMATION HAZARD

Age and sex distribution of subjects:

Age	Male	Female	Total
<20	10	12	22
20-29	47	29	76
30-39	10	8	18
40-49	3	2	5
50-59	1	1	2
60-69	0	0	0
70 above	0	0	0
Total	71	52	123

Prior knowledge of study:

21 Had some prior knowledge of study
102 Had no prior knowledge of study

Speeds that subjects say they normally drive, assuming "good weather": (MPH)

Freeways such as Interstate 5
(with old 70 mph speed)

$\overline{X}$ = 68.57
σ = 6.02
R = 60-85

Freeways such as Interstate 5
(with new 55 mhp speed)

$\overline{X}$ = 57.74
σ = 3.83
R = 50-65

Highways such as 99W
(with old Basic Rule 55 mph speed)

$\overline{X}$ = 57.39
σ = 5.52
R = 45-80

Highways such as 99W
(with new 55 mph speed)

$\overline{X}$ = 55.83
σ = 6.18
R = 45-80

Speeds that subjects say they would drive if they encountered some fog condition as during test: (MPH)

	70 MPH (I-5)	55 MPH (I-5)	Basic (99W)	55 MPH (99W)
$\overline{X}$ =	12.20	14.74	10.50	10.47
σ =	12.15	37.66	9.69	9.55
R =	0-75	0-60	0-60	0-60

Subject responses to ranking road hazards from 1 to 4 (1 being the most hazardous) while being in fog on a freeway such as I-5:

	$\overline{X}$	σ
Running off the road	2.63	1.16
Running into a stationary object or vehicle on the road	1.85	0.90
Overtaking a slow moving vehicle	2.86	1.08
Being overtaken by a faster vehicle	2.51	1.18

Subject responses to ranking road hazards from 1 to 4 (1 being the most hazardous) while being in fog on a highway such as 99W:

	$\overline{X}$	σ
Running off the road	2.31	1.15
Running into a stationary object or vehicle on the road	1.96	0.92
Overtaking a slower moving vehicle	2.94	1.07
Being overtaken by a faster vehicle	2.66	1.17

Reaction to reduced speed zones when encountered:

Comply with the speed	51
Tend to go faster than the required speed	65
Tend to go slower than the required speed	7

Faster than the required speed by: $\overline{X}$ 6.87
σ 2.25

Slower than the required speed by: $\overline{X}$ 8.93
σ 3.49

Sixty-three subjects said that they did not drive more cautiously during test runs than they would have if these had been just any stretch of highway. Sixty-three subjects said that they had driven more cautiously.

Response to whether or not posted speeds were reasonable:

Reasonable	62
Unreasonable	58
Sometimes reasonable	6

Unreasonable posted speeds:

Too high	60
Too low	3

More reasonable speed:

$\overline{X}$ = 10.67
σ = 9.02
R = 0-50

Distance from fog when first noticed there was fog on the road: (feet)

$\overline{X}$ = 232.10
σ = 295.02
R = 0-2000

One hundred nine subjects stated that they did attempt to slow down to the posted speed. Thirteen subjects stated that they made no attempt.

Twenty-eight subjects stated that they did attempt to drive through the fog at the posted speed. Ninety-four subjects stated that they did not.

Reasons why no attempt was made at driving through fog at posted speed:

Low visibility	39
Posted speed too fast	50
Posted speed too slow	3

Previous experience with driving in fog:

None at all	1
Very little (once or twice a year)	60
Frequently (five to ten times a year)	52
Over ten times a year	10

Types of road fog has been experienced on:

Freeways (such as I-5)	40
Highways (such as 99W)	63
Others	54

Driving tactics usually used in fog:

Follow another vehicle	53
Slow down	39
Stay in right lane	37
Dim headlights	14
Pull over and stop	11
Watch pavement stripes	63
Travel at consistent speed	2
Drive slowly on shoulder	2
Honk horn	1
Turn on flashers	3

Most noticeable reaction to fog:

EMOTIONAL REACTIONS	
Uncertainty	51
Caution	14
Afraid	31
Alert	5
Feeling lost	3
Surprise	7
Amazed	5
Mad	3

Where this reaction occurred:

As soon as fog was seen	9
Just before entering fog	47
Just as entered fog	65

Did you encounter other traffic on the road?

YES - 74 NO - 49

If yes, what type?

Vehicle ahead of me	21
Vehicle behind me	43
Both	11

Where did you encounter?

Before fog	74
In fog	5

Did the other traffic cause you concern or influence your driving in any way?

YES - 10 NO - 30

Most noticeable driving response to fog the first time it was encountered:

Slow down gradually	68
Slow down quickly	49
Watch pavement stripes	1
Stopped	5
Stick head out window	1

Lane used when driving through fog:

Right	82
Left	17
Both	25

One hundred and eighteen subjects used the pavement stripes to help being guided through the fog.

STRIPES USED -	Solid white	50
	Dashed white	60
	Yellow	24

STRIPES PREFERRED -	Solid white	4
	Dashed white	1
	Yellow	5

Difficulty maintaining position on the road:

Was difficult	65
Was not difficult	35
Sometimes difficult	25

When drivers did have difficulty, they tended to be:

Right of where they thought	25
Left of where they thought	43
Sometimes right, sometimes left	24

Difficulty maintaining position occurred:

Once	24
Twice	25
Three times	16
More than three	5

Location where difficulty of maintaining position occurred:

Shortly after entering fog	4
Beginning to middle of fog	4
Middle of fog zone	34
Middle to end of fog	13
Near the end of fog zone	11
Entire length of fog	15

Estimated average speed through fog: (MPH)

$\bar{X}$ = 7.84
σ = 6.40
R = 1-30

Use of windshield wipers:

YES - 75 NO - 46

Use of headlights:

YES - 119 NO - 1

Highbeam - 47 Lowbeam - 106

Response when asked whether fog was uniform or patchy:

Uniform - 60 Patchy - 64

Reaction to clear areas within fog bank:

Increase speed	32
Slow down	2
Try to get bearings	3
No reaction	20

Estimated visual range in fog: (feet)

$\bar{X}$ = 21.88
σ = 10.16
R = 0-200

Driver estimated safe speed for conditions encountered on this set of roads: (MPH)

$\bar{X}$ = 8.64
σ = 6.71
R = 0-30

On interstate freeways such as I-5: (MPH)

$$\bar{X} = 8.64$$
$$\sigma = 6.71$$
$$R = 0\text{-}30$$

On highways such as 99W: (MPH)

$$\bar{X} = 8.76$$
$$\sigma = 7.65$$
$$R = 0\text{-}40$$

I hope I never have to drive through anything like that again. I was really worried that an animal would be in front of me - if there was, I never would have seen it.

I've never seen anything like it before. Amazing.

It was more fog than I can handle.

You should try snow conditions.

I don't want to drive where that fog is considered "normal" driving.

It was interesting but the fog sure was intense.

Very strange.

Good Test Road.

I feel this type of study may help the Highway Department in preventing accidents under hazardous conditions.

This should be taken on film and shown to schools and have all new driving test to those getting a license for the first time.

I have never encountered fog as thick as this. I think it was a little unrealistic in that respect but I suppose it is possible. In a real situation like this, I may have tried to get off the road for a while and try to wait it out.

I would probably pull off the road and wait for fog to lift or lighten. Fog was very thick.

Good example of bad fog conditions.

I couldn't see anything in the fog and nearly ran off the road several times.

I thought it was very interesting. I have never drove in that thick of fog. It was quite an experience.

I thought the warning 25 mile sign very good idea (flashing).

Would like to see the results of this study.

Driving would be hazardous and extremely tense.

I would like a copy of the results of this survey when they are available.

I hope it makes the highways safer.

Interesting - I find I need to concentrate more on my driving than on vehicles behind me.

The flashing speed limit was very effective.

I enjoyed the thought of getting $26.00 for an hours worth of sitting.

Study was not prompt and had several long delays. Test area was good and very much realistic. Took one hour and 45 min. when it was supposed to take one hour.

I was told several times to be sure to be on time. I was early and still ended up 30 min. over.

I feel this was eye opening to me.

I couldn't see the 25 MPH sign until I was almost upon it. (and through the fog)

When can we do it again.

I was nervous about it but it wasn't bad.

Most fog banks tend to be thinner at the edges allowing time to slow as the car enters the fog. This fog was very thick from the beginning requiring rapid slowing.

Wow. The thickest fog I've ever been in. I think the pinto wagon was a Hwy. Division car because I noticed it parked on the side of the road to the left of the stop sign. If I am right, the car should be off the road before testers drive through and can spot it. Also branches and leaves on road, way that brush was arranged indicated presence of concealed test equipment.

Thickest fog I've ever driven in.

That was an excellent fog bank.

Couldn't see a thing.

At first I felt I could drive straight cause I knew the road was straight. I opened the door and saw I was way off.

Flashing sign (5 MPH) was very attention getting - so much so that I didn't notice the fog as soon as I should have - no speed reduction signs on return lane near dirt road cutoff.

The reflector didn't help much (on the side of the road). Reflectors on dashed and solid lines may help.

I would like to question on what basis do they have tests like these? Also, I would be interested in how many do they have on the average and the cost.

Roads such as I-5 have reflectors that I feel are great driving aids and would like to see them as much as possible.

I would like to see some results of this test when completed.

Haven't seen fog as thick as the densest of this - striping not visible much of the time. No other vehicles near enough for reference. Counter cables appear to cross road diagonally. I found myself attempting to cross them at right angles (in fog).

Very good fog. I wish an advanced driver training school was available to train those who wanted to more thoroughly.

The fog was more dense than any night fog I have ever encountered during 8 years in this area.

Have never before encountered fog so thick in such a location and under the prevailing weather conditions. If the fog had cleared slightly, I would have gone on slowly.

It was realistic. I didn't think the blinking white light with fog warning was visible enough.

Interesting as to the price paid per hour. (Great)

The flashing light was somewhat distracting, but maybe with common use this wouldn't bother me. I couldn't see the car behind me once I got into the fog - so it didn't affect me that much.

I tried to be as unbiased as possible, but because of the secret conditions and because it was a test, I knew something was going to happen but I didn't know what and I knew I wouldn't be harmed so I was more relaxed.

I tended to slow down for water on road in fogged area.

Wow - the shrubbery - It looks more like a country road with furry critters than I-5.

Wasn't as bad as I thought.

It was probably close to being real, but we were on our toes, although in the fog there was nothing much else to do but what I did.

It might be interesting to require some people to use left lane to see reaction.

I would like to emphasize the excellent visibility of the yellow line in the fog as opposed to the little visible white line.

The highway doesn't matter if you can't see, you can't see.

The process was well planned and continued smoothly.

Flashing fog sign caught attention. Black and silver 55 mph sign showed well so was aware of upcoming control sign.

This fog was more dense than any I have seen in normal driving - but it did provide a good test for reaction.

Fog lights worked very well, turned off headlights could see 5 times further.

In answering this questionnaire, I found out that there might be better ways to deal with fog conditions other than what I tried. All I can say is that I thought the fog would never end.

I liked the idea of the flashing speed sign. Would like to see solid yellow lines on both the outside of left lane and outside of right lane on a road such as I-5.

I think the study is a good idea. The fog was a little thick, I have encountered fog this thick only twice. Once I had to put someone in front with a flashlight to find the street.

I don't ever believe fog would be that thick.

Good test of my ability and reactions in different driving situations.

Install more highway line deflectors.

A well planned study. Fantastic job on fog simulation.

STUDY IV
SIGN STUDY

Age and sex distribution of subjects:

Age	Male	Female	Total
16 - 19	4	0	4
20 - 29	24	21	45
30 - 39	14	13	27
40 - 49	6	4	10
50 - 59	3	2	5
60 +	1	1	2
Total	52	41	93

Driving experience (years):

$\overline{X}$	(Average)	14.53
σ	(Standard Deviation)	9.2
R	(Range)	1-42

Average miles driven per year:

$\overline{X}$	10,500
σ	5.750
R	200 - 25,000

Prior knowledge of study:

82 Had prior knowledge of study
11 Had no prior knowledge of study

Speeds that subjects say they normally drive, assuming "good weather":

Freeways such as Interstate 5
(with old 70 mph speed)

	High	Low
$\overline{X}$ =	66.75	65.89
σ =	4.81	5.33
R =	60-75	55-75

Freeways such as Interstate 5
(with new 55 mph speed)

	High	Low
$\bar{X}$ =	57.67	56.64
σ =	3.37	2.64
R =	50-65	50-67.5

Highways such as 99W
(with old Basic Rule 55 mph speed)

	High	Low
$\bar{X}$ =	55.74	55.26
σ =	5.82	3.72
R =	42.5-67.5	50-60

Highways such as 99W
(with new 55 mph speed)

	High	Low
$\bar{X}$ =	52.93	53.48
σ =	9.16	8.17
R =	42.5-60	45-60

Speeds that subjects say they would drive is they encountered the same fog conditions as during the test:

Freeways such as Interstate 5
(with old 70 mph speed)

	High Visibility	Low Visibility
$\bar{X}$ =	18.98	10.26
σ =	10.26	11.43
R =	0-50	0-60

Freeways such as Interstate 5
(with new 55 mph speed)

	High Visibility	Low Visibility
$\bar{X}$ =	18.98	10.69
σ =	10.26	10.64
R =	0-50	0-57.5

Highways such as 99W
(with old Basic Rule 55 mph speed)

	High Visibility	Low Visibility
$\overline{X}$ =	15.21	9.43
σ =	8.51	9.82
R =	0-45	0-52.5

Highways such as 99W
(with new 55 mph speed)

	High Visibility	Low Visibility
$\overline{X}$ =	15.21	9.43
σ =	8.51	9.82
R =	0-45	0-52.5

Ranking of fog hazards on freeway:

Running off the road.
Overtaking a slower moving vehicle.
Being overtaken by a faster moving vehicle.
Running into a stationary object or vehicle on the road.

Ranking of fog hazards on highways:

Overtaking a slower moving vehicle.
Being overtaken by a faster moving vehicle.
Running off the road.
Running into a stationary object or vehicle on the road.

When encountering reduced speed zone on highway, do you usually:

Comply with the speed
Go faster than posted speed
Go slower than posted speed

Sixty-one subjects said that they did not drive more cautiously during test runs than they would have if these had been just any stretch of highway. Thirty-two subjects said that they had driven more cautiously.

Thirty-two subjects said the speed posted prior to fog was reasonable; twenty-eight subjects said it was too high, and six said it was too low.

Distance from fog when first noticed there was fog:

$$\bar{X} = 35.01 \text{ feet}$$
$$\sigma = 17.96 \text{ feet}$$
$$R = 0 - 375 \text{ feet}$$

Twenty-nine subjects said they attempted to maintain the posted speed through the fog. The remaining 30 subjects did not.

Previous experience with driving fog:

None	=	2
Occasionally (once or twice a year)	=	42
Frequently (5 to 10 times a year)	=	49

Types of roads fog has been experienced on:

Highway (such as 99W)	54
Freeway (such as Interstate 5)	21
Residential	7
County	4
Coastal	3
Mountain	1
All Types	3

Driving tactics usually used in fog:

Follow other vehicles	36
Drive slower	18
Follow center line stripe	8
Follow right shoulder stripe	8
Drive in right lane	6
Follow pavement stripes	6
Pull off and stop	6
Dim headlights	4
Drive in left lane	1

Most noticeable reaction to fog the first time it was encountered during test runs:

Emotional Reactions		Driving Reactions	
Uncertainty	40	Slowed down	82
Fear	25	Drive with extreme care	6
Surprise	12	Brought car to complete stop	5
Amused	9		
Caution	7		

Where these reactions occur:

	Emotional Reactions	Driving Reactions
Just before entering fog	23	11
Just as entering fog	40	46
When in fog	30	36

Lane used when driving through the fog:

Right	62
Left	20
Both	11

Use of painted lines as guides in fog:

Yes 84 No 5 Sometimes 4

Which line?

Yellow 19 Dashed White 32 Solid White 41

One could not see the lines

Experienced difficulty maintaining position on road:

Yes 37 No 35 Sometimes 21

Relative position:

Too far right	7
Too far left	43
Sometimes right, sometimes left	6

Estimated average speed through fog:

	High Visibility	Low Visibility
$\overline{X}$ =	11.85	8.77
σ =	4.66	5.91
R =	1-22.5	2-22.5

Use of windshield wipers:

Yes 54 No 39

Use of headlights:

Low-beam	68
High-beam	6
Tried both	17
Parking lights & low-beams	2

Uniformity of fog:

Uniform	51	Patchy	42

Response to clear areas within fog bank:

Maintain speed	39
Increase speed	27
None	24
Slow down	3

Estimate of visual range in fog:

	High Visibility	Low Visibility
$\overline{X}$ =	17.17	19.80
=	14.64	59.37
R =	1-60	0-375

Driver's estimate of safe speed for conditions encountered:

Test Road

	High Visibility	Low Visibility
$\overline{X}$ =	13.22	8.35
=	9.69	7.70
R =	0-55	0-45

Interstate Freeway (such as Interstate 5)

	High Visibility	Low Visibility
$\overline{X}$ =	17.44	9.96
=	12.14	9.65
R =	0-65	0-52.5

Highway (such as 99W)

	High Visibility	Low Visibility
$\overline{X}$ =	14.50	8.25
=	10.08	7.93
R =	0-55	0-47.5

General Comments:

Fog was thick. Never driven in anything as dense.

Interesting. I relate it to Murder Creek. Questionnaire might include moving and collisions subject might have had.

On I-5 one has to worry about being rear-ended.

Can't driver much faster than 15 MPH in fog even on Interstate 5.

Fog was scary!

Fog was frightening. Sense of right and left vanished, yellow line was the only thing that kept me on the road. Most interesting.

Thought you should have checked lights, brakes and windshield wipers used as a safety measure on test vehicles.

The road should be longer so we could get up to the 55 MPH speed limit.

Would like to see the final report on results.

I hope I never see that kind of fog on the road.

Fog was unrealistically thick.

Nice fog bank - how much does this cost?

Was interesting and I enjoyed it.

I was less concerned about fog than normal because I knew road was straight and I was the only one on it.

Reflectors in road and newly painted lines would help keep cars on road under control at 15 MPH. Very dangerous otherwise in that dense fog.

It was interesting. Hopefully some improvement in proper warning signs will come out of it.

I have never driven in fog as thick as this.

Fog was thickest I've ever seen. Being told to continue without stopping was nerve wrecking under similar conditions elsewhere I would have stopped. Broadcasted speed of 15 MPH was definitely too fast through fog.

I thought it was scarey and never want to be in such thick fog again.

Make fog thinner. I've never seen it that thick.

Worst fog I've ever seen.

If I had been on a public road I would have pulled off and stopped.

The fog seemed extreme compared to what I've driven in. It was impossible to see the road at all.

Heaviest fog I have seen.

Fog wasn't long enough.

Have markers - reflectors on side of road.

Not long enough course. Better to have one or two flashing signs than the number you have.

Roads should be lined on both sides with reflectors and in center.

Yellow line is much easier to see rather than white.

The factor most limiting speed was the ability to see well enough to stay on the road. Better roads would not have allowed an increase in speed given the same visibility.

The fog on the back stretch took me by surprise. I don't think it belonged there.

Great experience - liked the warning lights.

Very interesting, would like to see the results.

Forgot to switch to low beams, which would have helped. Because he was caught up in trying to guide his way.

More aids can be developed to cope with thick fog. Field burning smoke, etc. Fog was good experience.

Would have liked to experience fog conditions closer to curve in road to see if signs were noticeable.

Fantastic.

If road conditions on I-5 or 99W were this bad, I wouldn't be driving them. Very interesting experience.

I'm uneasy in fog as I'm unexperienced with it. It is scary.

Interesting research project.

Very interesting.

Interesting study. Road not realistic of freeway.

Last line on the sign was too small.

STUDY V
DELINEATION STUDY

Age and sex distribution of subjects:

Age	Male	Female	Total
16 - 19	2	2	4
20 - 29	25	18	43
30 - 39	2	2	4
40 - 49	2	3	5
50 - 59	1	1	2
Total	32	26	58

Driving experience (years):

$\bar{X}$	(Average)	11.3
σ	(Standard Deviation)	8.2
R	(Range)	0.5-40

Average miles driven per year:

$\bar{X}$	11,050
σ	7,489
R	1,000-42,000

Prior knowledge of study:

8 Had prior knowledge of study
50 Had no prior knowledge of study

Speeds that subjects say they normally drive, assuming "good weather":

Freeways such as Interstate 5
(with old 70 mph speed)

$\bar{X}$ = 67.59
σ = 6.32
R = 50 - 80

Freeways such as Interstate 5
(with new 55 mph speed)

$\bar{X}$ = 57.53
σ = 4.14
R = 50 - 70

Highways such as 99W
(with old Basic Rule 55 mph speed)

$\bar{X}$ = 56.58
σ = 5.01
R = 50 - 70

Highways such as 99W
(with new 55 mph speed)

$\bar{X}$ = 55.77
σ = 4.30
R = 50 - 70

Speeds that subjects say they would drive if they encountered the same fog conditions as during the test:

Freeways such as Interstate 5
(with old 70 mph speed)

	High Visibility	Low Visibility
$\bar{X}$ =	17.03	15.72
σ =	7.92	8.49
R =	5-40	3-45

Freeways such as Interstate 5
(with new 55 mph speed)

	High Visibility	Low Visibility
$\bar{X}$ =	16.82	15.75
σ =	7.79	8.49
R =	5-40	3-40

Highways such as 99W
(with old Basic Rule 55 mph speed)

	High Visibility	Low Visibility
$\bar{X}$ =	15.47	13.92
σ =	7.44	7.19
R =	5-40	3-40

Highways such as 99W
(with new 55 mph speed)

	High Visibility	Low Visibility
$\bar{X}$ =	15.09	13.92
σ =	7.64	7.19
R =	5-40	3-40

Ranking of fog hazards on freeway:

1. Running into a stationary object or vehicle on the road.
2. Being overtaken by a faster moving vehicle.
3. Overtaking a slower moving vehicle.
4. Running off the road.

Ranking of fog hazards on highways:

1. Running into a stationary object or vehicle on the road.
2. Running off the road.
3. Being overtaken by a faster moving vehicle.
4. Overtaking a slower moving vehicle.

When encountering reduced speed zone on highway, do you usually:

Comply with the speed	28
Go faster than posted speed	27
Go slower than posted speed	3

Forty-six subjects said that they did not drive more cautiously during test runs than they would have if these had been just any stretch of highway. Twelve subjects said that they had driven more cautiosly.

Forty subjects said the speed posted prior to fog was reasonable; 14 subjects said it was too high, and four said it was too low.

Distance from fog when first noticed there was fog:

$$\bar{X} = 327.73 \text{ feet}$$
$$\sigma = 325.40 \text{ feet}$$
$$R = 0\text{-}1500 \text{ feet}$$

Forty-one subjects said they attempted to slow to the indicated speed when the lights on the fog sign(s) flashed. Five subjects said they did not attempt to slow and 12 subjects apparently misunderstood the question.

Twenty-four subjects said they attempted to maintain the posted speed through the fog. The remaining 34 subjects did not.

Previous experience with driving in fog:

None	=	1
Occasionally (once or twice a year)	=	25
Frequently (5 to 10 times a year)	=	29
More than 10 times a year	=	3

Types of roads fog has been experienced on:

Freeways (such as Interstate 5)	17
Highways (such as 99W)	34
Residential	3
Country	4
Coastal	2
Mountain	2
All types	7

Driving tactics usually used in fog:

Follow other vehicle	36
Drive slower	17
Drive in right lane	13
Follow pavement stripes	6
Follow center line stripe	5
Follow right shoulder stripe	4
Pull off and stop	3
Watch edge of highway	2
Drive with windshield wiper on	1
Use flashers	1
Dim headlights	1
Drive in left lane	1
Watch for sight posts	1

Most noticeable reaction to fog the first time it was encountered during test runs:

Emotional Reactions		Driving Reactions	
Uncertainty	23	Slowed down	51
Amused	2	Drove with extreme care	5
Helplessness	3		
Surprise	5		
Fear	13		
Caution	5		
Tension	3		

Where these reactions occur:

Just before entering fog	22
Just as entered fog	18
When in fog	13

Was signing adequate for the conditions encountered:

High Signing Case				Low Signing Case			
Adequate	27	Inadequate	8	Adequate	8	Inadequate	14

Reasons for inadequacy:

High Signing -	Could not see signs	2
	Too many lights	1
	Too many signs	2
	Need signs on both sides of road	1
Low Signing -	Need more lights	9
	Need more signs	5

Were reflective center line and edge line buttons helpful:

High Density Button Case

26 YES 0 NO

Low Density Button Case

27 YES 5 NO

All five subjects who said buttons were not helpful indicated that buttons should have been closer together.

Lane used when driving through the fog:

Right	52
Left	5
Both	1

Use of painted lines as guides in fog:

Yes 40 No 8 Sometimes 10

Which line:

Yellow 14 Dashed White 17 Solid White 18

Experienced difficulty maintain position on road:

Yes 5 No 37 Sometimes 16

Relative position:

Too far right	7
To far left	11
Sometimes right, sometimes left	3

Estimate average speed through fog:

		High Visibility	Low Visibility
$\overline{X}$	=	13.45	12.15
σ	=	5.52	5.48
R	=	5-25	3-25

Use of windshield wipers:

Yes	25
No	34

Use of headlights:

Low-beam	39
High-beam	3
Tried both	15
Parking lights	1

Uniformity of fog:

Uniform	29	Patchy	29

Response to clear areas within fog bank:

Maintain speed	13
Increase speed	13

Estimate of visual range in fog:

		High Visibility	Low Visibility
$\overline{X}$	=	13.23'	7.15'
σ	=	10.29'	4.49'
R	=	2-40	1-15

Driver's estimate of safe speed for conditions encountered:

		Test Road	
		High Visibility	Low Visibility
$\overline{X}$	=	13.48 mph	11.11 mph
σ	=	5.66	5.37
R	=	5-40	0-25

		Interstate freeway (such as Interstate 5)	
		High Visibility	Low Visibility
$\overline{X}$	=	16.44 mph	12.85 mph
σ	=	8.22	6.55
R	=	5-35	0-35

Highway (such as 99W)

		High Visibility	Low Visibility
$\overline{X}$	=	13.68 mph	11.23 mph
σ	=	6.61	5.08
R	=	5-35	0-30

General comments:

Too many signs of which the surface was difficult to see. Reflectors were much easier to see than painted lines.

I am curious if the big sign board like on I-5 by Western Kraft would have worked in dense fog such as this.

Fog was too dense compared to roads or highways.

We need better markers and lines on the road.

Pretty thick fog at times.

Very realistic except you know there are no other cars on the road.

I prefer to keep away from fog.

Should have made real conditions - fake an accident - have a two-way road, etc.

The signs were too small.

I felt secure because I knew there were no cars on the highway.

Reflective dots definitely helped in the fog.

Found raised reflectors extremely helpful.

Why do they do it at night?

Found reflectors very helpful in fog.

Yellow lights useless in fog. White buttons dim. Need more reflective power.

Almost hit a skunk.

Would have liked to have more than one run through the fog.

Fog signs could be set farther apart.

Feel it could be very beneficial.

STUDY VI
CRY WOLF

Age and sex distribution of subjects:

Age	Male	Female	Total
16 - 19	2	2	4
20 - 29	10	10	20
30 - 39	1	0	1
40 - 49	1	0	1
50 - 59	1	1	2
60 +	2	0	2
Total	17	13	30

Driving experience (years):

$\overline{X}$	(Average)	12.77
σ	(Standard Deviation)	11.11
R	(Range)	2-40

Average miles driven per year:

$\overline{X}$	10,700
σ	8.060
R	1,000 - 4,000

Prior knowledge of study:

24 Had no prior knowledge of study
6 Had prior knowledge of study

Speeds that subjects say they normally drive, assuming "good weather":

Freeways such as Interstate 5
(with old 70 mph speed)

$\overline{X}$ = 67.10
σ = 5.38
R = 55 - 75

Freeways such as Interstate 5
(with new 55 mph speed)

$\overline{X}$ = 58.17
σ = 3.02
R = 52 - 62

Highways such as 99W
(with old Basic Rule 55 mph speed)

$\bar{X}$ = 55.37
σ = 3.60
R = 50 - 65

Highways such as 99W
(with new 55 mph speed)

$\bar{X}$ = 54.72
σ = 3.85
R = 50 - 65

Ranking of fog hazards on freeway:

Running into a stationary object or vehicle on the road.
Being overtaken by a faster moving vehicle
Overtaking a slower moving vehicle
Running off the road

Ranking of fog hazards on highways:

Running into a stationary object or vehicle on the road.
Overtaking a slower moving vehicle
Being overtaken by a faster moving vehicle
Running off the road

When encountering reduced speed zone on highway, do you usually:

Comply with the speed	11
Go faster than posted speed	17
Go slower than posted speed	2

Nineteen subjects said that they did not drive more cautiously during test runs than they would have if these had been just any stretch of highway. Eleven subjects said that they had driven more cautiously.

Previous experience with driving in fog:

None	2
Occasionally (once or twice a year)	8
Frequently (5 to 10 times a year)	20

Types of roads fog has been experienced on:

Highways (such as 99W)	15
Freeways (such as Interstate 5)	6
Residential	2
County	1
All types	5

Driving tactics usually used in fog:

Follow other vehicles	11
Drive slower	11
Follow center line stripe	1
Follow right shoulder stripe	1
Drive in right lane	4
Follow pavement stripes	2
Pull off and stop	2
Dim headlights	6
Drive in left lane	0

ONLY THE SIX SUBJECTS THAT ACTUALLY ENCOUNTERED FOG WERE ASKED TO ANSWER THE FOLLOWING QUESTIONS:

Speeds that subjects say they would drive if they encountered the same fog conditions as during the test:

Freeways such as Interstate 5
(with old 70 mph speed)

$\overline{X} = 19.17$
$\sigma = 5.85$
$R = 10 - 30$

Freeways such as Interstate 5
(with new 55 mph speed)

$\overline{X} = 19.17$
$\sigma = 5.85$
$R = 10 - 30$

Highways such as 99W
(with old Basic Rule 55 mph speed)

$\overline{X} = 19.17$
$\sigma = 5.85$
$R = 10 - 30$

Highways such as 99W
(with new 55 mph speed)

$\bar{X}$ = 19.17
σ = 5.85
R = 10 - 30

All six subjects said the speed posted prior to fog was reasonable.

Distance from fog when first noticed there was fog:

$\bar{X}$ = 628 feet
σ = 466 feet
R = 72 - 1200 feet

Five subjects said they attempted to maintain the posted speed through the fog. The remaining subject did not.

Most noticeable reaction to fog the first time it was encountered during test runs:

Emotional Reactions		Driving Reactions	
Uncertainty	2	Slowed down	4
Fear	1	Drive with extreme care	2
Surprise	1		
None	2		

Where did these reactions occur:

	Emotional Reactions	Driving Reactions
Just before entering fog	1	2
Just as entered fog	2	3
When in fog	1	1

Lane used when driving through the fog:

Right	6
Left	0
Both	0

Use of painted lines as guides in fog:

Yes 6 No 0 Sometimes 0

Which line:

Yellow 1 Dashed white 3 Solid white 2

Experienced difficulty maintaining position on road:

Yes 4 No 2

Relative position:

Too far left 3
Sometimes right, sometimes left 1

Estimated average speed through fog:

$\overline{X}$ = 13.60
σ = 2.19
R = 10 - 15

Use of windshield wipers:

Yes 4 No 1

Use of headlights:

Low-beam 5 High-beam 1

Uniformity of fog:

Uniform 3 Patchy 3

Response to clear areas within fog bank:

Maintain speed	0
Increase speed	0
None	3
Slow down	0

Estimate of visual range in fog:

$\overline{X}$ = 14.0 feet
σ = 7.04 feet
R = 5-20 feet

Driver's estimate of safe speed for conditions encountered:

Test Road

$\overline{X}$ = 14.50
σ = 3.17
R = 10-20

Interstate Freeway (such as Interstate 5)

$\bar{X}$ = 19.50
= 6.71
R = 10-30

Highway (such as 99W)

$\bar{X}$ = 17.50
= 5.00
R = 10-25

General Comments

Need more reflectors on road.

Signs didn't make sense - No Fog.

Not sure what it was testing.

Interesting - too many questions about fog when you encountered none.

Dull

Without fog it was boring. Wish you had an outhouse.

No Fog.

Track should have been longer.

Hard to slow to 15 MPH when no fog.

Glad to see research being done on fog.

I really appreciate good road lining and buttons. It makes a big difference when you encounter fog or other hazards.

There was no fog. I encountered a buck on two of the runs.

I would like to have encountered the fog.

I couldn't figure out what you wanted me to do.

Appendix J

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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